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Technical Assessment Report for Abyssal Plains Waste Isolation Project

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The Department of Defense's Naval Research Laboratory (NRL) has been tasked by the Strategic Environmental Research and Development Program (SERDP) to assess the environmental viability of the isolation of dredged material, sewage sludge, and municipal incinerator fly ash on the abyssal plains of the deep ocean. Abyssal Plains Waste Isolation (APWI) is the term given by this project to the isolation of waste on the abyssal plains. Oceaneering Technologies (OTECH) has been tasked by NRL to assess waste handling technologies regarding engineering feasibility and reliability.

The technical assessment of candidate waste handling technologies consisted of a three part process. First, through a series of patent research, brainstorming new ideas, and a methodical down-select and evaluation exercise, five concepts were chosen to be evaluated. Technical issues of these five concepts were then identified and explored as the second major process step. Lastly, a risk assessment of these concepts was performed to determine overall technical and operational feasibility.

The five system concepts are referred to, in this report, as: Surface Emplacement, Remotely Operated Vehicle (ROV) Glider, Direct Descent Disk, Pipe Riser, and Tethered Container. To eliminate repetition, elements common to all system concepts, such as transporter systems, containers, handling systems, and waste specific gravity were researched separately.

This technical assessment report is the second in a series of three reports submitted to NRL by OTECH. The first report covered the system level requirements which all candidate waste handling technologies must meet. This technical assessment report will be followed by a Rough Order of Magnitude (ROM) cost analysis of the most viable APWI system concepts.

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ABSTRACT

The Department of Defense's Naval Research Laboratory (NRL) has been tasked by the Strategic Environmental Research and Development Program (SERDP) to assess the environmental viability of the isolation of dredged material, sewage sludge, and municipal incinerator fly ash on the abyssal plains of the ocean floor. Abyssal Plains Waste Isolation (APWI) is the term given by this project to the isolation of waste on the abyssal plains. Oceaneering Technologies (OTECH) has been tasked by NRL to assess waste handling technologies regarding engineering feasibility and reliability.

The technical assessment of candidate waste handling technologies consisted of a three part process. First, through a series of patent research, brainstorming new ideas, and a methodical down-select and evaluation exercise, five concepts were chosen to be evaluated. Technical issues of these five concepts were then identified and explored as the second major process step. Lastly, a risk assessment of these concepts was performed to determine overall technical and operational feasibility.

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This technical assessment report is the second in a series of three reports submitted to NRL by OTECH. The first report covered the system level requirements which all candidate waste handling technologies must meet. This technical assessment report will be followed by a Rough Order of Magnitude (ROM) cost analysis of the most viable APWI system concepts.

PREFACE

This technical analysis report summarizes the results of an engineering study effort to develop and analyze the technical feasibility of conceptual approaches to provide means for Abyssal Plains Waste Isolation (APWI) of dredged material, sewage sludge and municipal incinerator fly ash at identified APWI sites.

All existing patents (U.S. and foreign) related to deep ocean isolation of various materials were examined as the baseline for previous work. By combining common approaches, concepts in 128 patents were reduced to 30 concepts for evaluation. These 30 were then evaluated against high level technical, environmental, and cost criteria to determine their relative merit. Five of these concepts were selected for further definition and evaluation. Engineering assessments used to identify and evaluate technical issues and their resolution are contained in this report.

To be acceptable, the concepts must comply with design constraints identified in the Systems Level Requirements Report and imposed by environmental regulations, waste stream properties, weather and site conditions and existing regulatory constraints on vessels. The system level requirements report, OTECH's technical analysis of the APWI concepts, and a cost estimate of the viable concepts will be used together by NRL for its study of the advantages, disadvantages, and economic and environmental viability of storing these waste streams on the abyssal seafloor.

This research was funded under contract number N00014-94-C-6009. Dr. Philip Valent (NRL) is the Principal Investigator and Mr. Martin Fagot is the Contracting Office's Technical Representative (COTR) at NRL for this project.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES AND TABLES

FIGURES

TABLES

1.0 SUMMARY

OTECH has identified four APWI concepts which provide technically feasible approaches for isolation of waste on the abyssal plains of the ocean.

Abyssal Plains Waste Isolation (APWI) is the isolation of three waste streams (dredged materials, sewage sludge, and municipal incinerator fly ash) on the abyssal plains of the ocean without waste loss in the intervening water column. This technical report summarizes analyses performed to identify, refine, and evaluate options of material preparation, transportation, and emplacement of these three waste streams on the abyssal plains.

The initial method used to identify potential options or concepts of abyssal emplacement was to perform a broad-based patent search to identify existing technologies and concepts of ocean isolation. Since this approach generated a large number of concepts, a trade-off analysis was used to narrow the number of concepts down to the best APWI concepts. As a result of the down-selection from 128 to seven "winning concepts", followed by the synthesis of the similar technologies of these seven concepts, five APWI concepts were chosen to further define and evaluate. These concepts were:

- Surface Emplacement - A customized barge is designed with 51 separate cells, which are lined with disposable, high strength, high density, flexible bags. The waste material is loaded into the individual bags, and the bags closed before leaving port. The vessel then transits to the APWI site, opens the trap doors to release the bags, which free-fall to the seabed. The bag isolates the material from the intervening water column during descent. After impact with the bottom, the material remains contained in the bag. Experiments conducted by the U.S. Army Corps of Engineers (COE) has demonstrated that these types of bags do not burst upon landing on the seafloor.

- ROV Glider - A submersible remotely operating vehicle (ROV Glider) is used to transport material to the abyssal isolation site, submerge, release the waste at a specified altitude, and return back to the surface for recovery. Similar to Surface Emplacement, the Glider contains individual compartments lined with flexible bags. The Glider is negatively buoyant when loaded with waste, so it is towed to the APWI site in a floating "garage". At the site, the ROV Glider is released from its "garage" and descends in an actively-controlled, spiral-shaped flight path until it nears the seafloor. Its trap doors open, the containerized load falls out, and the now positively buoyant Glider returns to the surface. The ROV Glider is then recovered by the surface ship into its "garage." The ROV Glider is autonomously controlled, but can be minimally controlled from the surface as a backup mode.

- Direct Descent Disk - A vessel in the shape of a large diameter, shallow disk delivers its cargo to a predetermined altitude off the seafloor and then releases it. The Disk also has numerous cargo cells lined with bags. It is negatively buoyant when loaded with waste. It is transported to the site in a "floater module" and, when released, descends in a near-vertical path to near the seafloor, brakes, releases its containerized load via trap doors, becomes positively buoyant, and ascends to the surface. In contrast to the ROV Glider, the Direct Descent Disk does not follow a closed-loop controlled glidepath. Its inherently stable hydrodynamic design allows it to perform the operation without active stabilization.

- Pipe Riser - A set of four large diameter pipes run vertically from the ocean surface to near the seafloor to transport waste to the abyssal isolation site. A transport ship hauls the waste material in bulk from the port to the APWI site, where it is pumped to the riser for dilution with cold water prior to disposal.

Two pipes bring cold water from 700 m depths to slurryize and thermally equalize the waste with the abyssal ocean temperature. The slurryized waste travels down the other two pipes, isolating it from the water column, where it is discharged near the bottom to form a mound on the seafloor. The pipe riser is dynamically positioned at the top and moored at the bottom to maintain station.

- Tethered Container - A ship is loaded with bulk waste at port and transits to the APWI site. A large on-board rigid container is then loaded with bulk waste and lowered by winch from the ship to near the seafloor. At this point, the bottom of the container is opened and waste falls out to form a mound on the seafloor. The container is hauled back to the surface platform to be refilled and the cycle repeated.

Along with the issues unique to each concept, some issues are common to all concepts. These common issues include:

- Transporter System:
  Research of waste stream geographical distribution and existing port facilities has determined that a bulk carrier ship of 25,000 DWT capacity would be suited for use in all U.S. coastal regions. These ships would be capable of 15 knot speeds with a range in excess of 2000 nautical miles (nmi).

- Handling Systems:
  Mechanical handling systems have the capability of loading any APWI concept at 4800 metric tons (Mg)/hr.

- Waste Stream Containers:
  Flexible geotextile bags were chosen to encapsulate the waste material for three of the concepts.

- Port Facilities:
  Research of existing port facilities and docking spaces yielded 125 candidate docking sites large enough for the APWI concepts.

- Applicability of APWI Concepts with Waste Streams:
  The three waste streams have different physical characteristics that must be accommodated by the APWI concepts. An effort was made to minimize the amount of waste stream preprocessing in order for it to be compatible with the individual concepts. The most significant parameter was handling characteristics, dominated by percentage solids.

- Isolation Site Capacity:
  Isolation site storage capacity of 4.5 million metric tons based upon four hundred 500 m X 500 m square grids, within a 10 km X 10 km designated site location, totaling 1,800 million metric tons per Atlantic, Gulf of Mexico, or Pacific APWI site location.

As each of the concepts were evaluated, many technical issues surfaced. These issues were identified and documented in this report. Depending on the complexity of the issue, some were resolved and others were not. A list of unresolved technical issues is provided along with the proposed method of solution. Each of the concepts requires development of large scale marine equipment to handle the magnitude of the three waste steams.

The defined APWI concepts were compared to the system level requirements documented in Marcy et al. (1994). The Tethered Container concept was disqualified at this point because a handling system capable of emplacing

the required amount of waste per system per year was not technically feasible. All system level requirements can be met by the remaining four concepts. With respect to the environmental regulatory requirements, a list of existing U.S. regulations and international agreements which impact on the APWI approach is included in this report.

Two independent reliability analyses, Fault Tree Analysis and Failure Modes Effects and Criticality Analysis (FMECA) were performed on the remaining four APWI concepts. The results of these analyses provided a ranking of the four systems according to combined technical and operational risk. In order of increasing risk, they are:

- Surface Emplacement
- Direct Descent Disk
- ROV Glider
- Pipe Riser

Of the failure modes identified, all can be overcome by adding redundancy in the design. Areas requiring additional study, modeling and/or testing were identified for each concept as a result of the reliability analyses. These are critical areas which require close control during development. The recommendations for additional study of these areas has been provided. The result of this study is four concepts which provide technically feasible alternatives to current waste management methods. When combined with technical and operational risk, the following conclusions are reached:

- Surface Emplacement offers the least complex, most reliable system for large scale, long term deep ocean isolation. The drawbacks to this concept are the probable scattering pattern of the bags during emplacement and potential infrequent ripping of waste-filled bags by metal edges in the barge loading and releasing processes. It is expected that early demonstrations to assess environmental impact will necessitate that bags be grouped into piles on the seafloor to simulate long term emplacement operations. Therefore, this concept appears to be most viable for full scale operation, but not conducive for near term demonstration and environmental experimentation.

- For near term demonstrations and experiments, as discussed above, the Direct Descent Disk appears to be the most practical approach for emplacement of waste in clusters. It requires the least amount of active control of the remaining concepts and can be easily modeled and scale tested for a quick development and validation program. It also can be configured for surface release. This feature is beneficial for large scale surface experiments. It could be used in a production mode to emplace highly contaminated waste near the seafloor.

2.0 INTRODUCTION

OTECH has employed a systems engineering approach to assess the APWI concepts as to engineering feasibility and reliability.

The Strategic Environmental Research and Development Program (SERDP) tasked the Naval Research Laboratory (NRL) to assess advantages, disadvantages, and environmental viability of storing dredged material, sewage sludge, and municipal incinerator fly ash on the abyssal plains of the ocean. This study is called the Abyssal Plains Waste Isolation (APWI) Project. NRL has six objectives in assessing the storage of waste on the abyssal plains.

1. Identify environmental characteristics of abyssal plains which affect suitability for waste isolation;
2. Select abyssal plain areas offering most promise of achieving waste isolation;
3. Assess candidate waste emplacement concepts as to engineering feasibility and reliability;
4. Develop a survey plan to obtain a baseline of the physical, chemical, biological, and geological characteristics of a suitable area;
5. Prepare a monitoring program plan; and
6. Conduct an economic analysis of the deep ocean isolation concepts.

Oceaneering Technologies (OTECH) was tasked by NRL to assess concepts as to engineering feasibility and reliability (objective number three above). OTECH has divided this objective into three tasks:

1. System Requirements
2. Technical Assessment
3. Economic Viability

This report deals only with task number two, Technical Assessment. The Technical Assessment report deals with the down-selection, synthesis, concept definition, and reliability assessment of concepts. The system requirements presented in Marcy et al. (1994) were used for the down-selection criteria and assessment of these technologies. Figure 2.0-1 shows the relationship of these task reports as related to OTECH's system engineering technical approach. The shaded area includes information presented in this report.

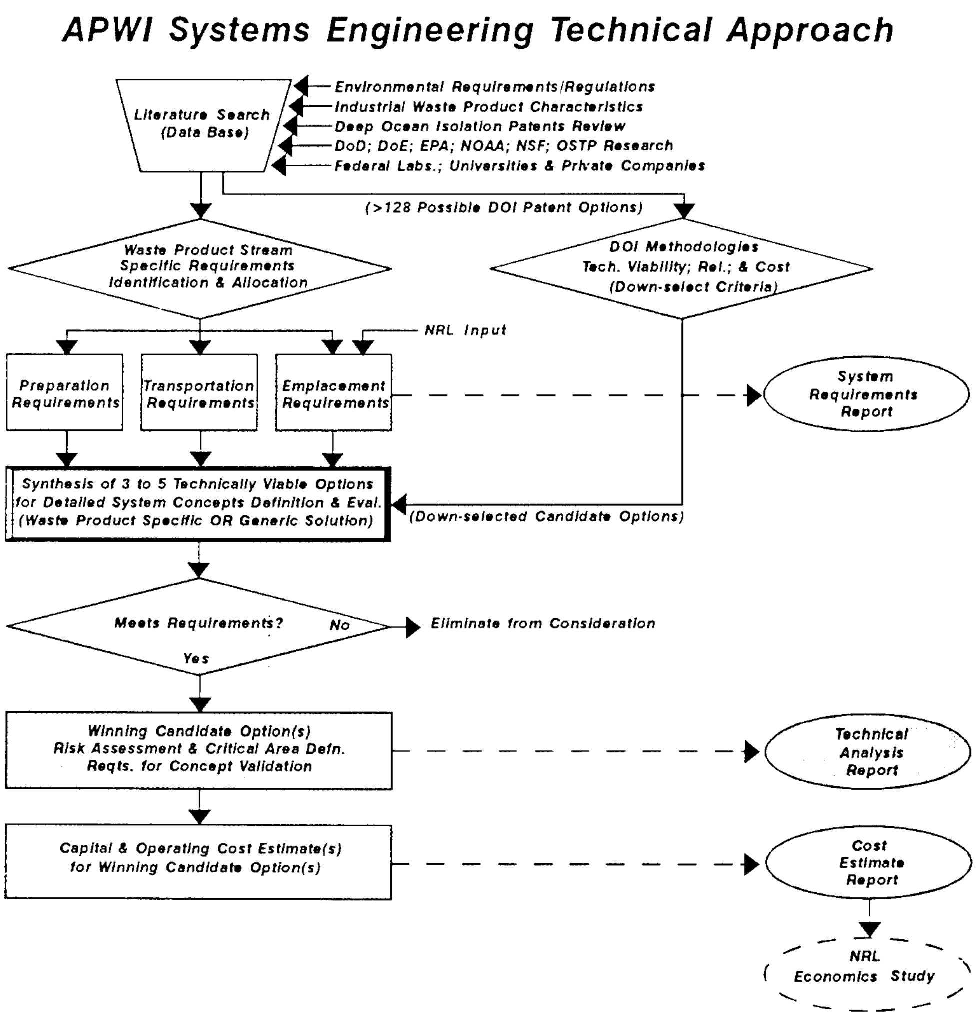


Figure 2.0-1
APWI Systems Engineering Approach

The down-selection process employed a comprehensive patent search leading to patents dealing with the concept of ocean waste isolation and subsequent evaluation of these patents to identify those most applicable to APWI. The winning concepts from the down-selection process were defined, evaluated, and refined to determine their viability for APWI. Figure 2.0-2 shows the flow of the down-selection process, synthesis of concepts, and top level engineering evaluation applied to the APWI concepts.

As shown in the Figure 2.0-2, each APWI concept was examined separately, but to prevent an overlapping of effort, those elements common to all concepts such as transporter system, handling system, waste stream containers, docking space, interface of APWI concepts with waste streams, and isolation site capacity were researched at one time.

As part of the top level engineering phase, the concepts were judged against the system level requirements generated in the system requirements report. System level requirements are the constraints placed upon an APWI concept by:

- Environmental regulations,
- Physical, chemical, and biological properties of waste,
- Volumes of waste generated,
- Environmental conditions encountered from port to site,
- Site characteristics, and
- General regulatory design constraints for vessels.

Concepts must adhere to the system level requirements while handling the three waste streams. These requirements are applicable to all waste streams, providing extremely low or no risk of contamination between port and final emplacement.

As a last step in this technical assessment process, the viable APWI concepts were assessed by two reliability analyses. These analyses were used as a comparison between these concepts regarding technical risk and also to identify areas which require further study.

Since the technology incorporated in the concepts spanned many technical fields, all issues raised could not be answered fully by OTECH personnel. For input and analyses on technical issues, external sources with expertise in those fields were used. The technical issues addressed by these consultants included hydrodynamic analyses, catenary analyses, naval architecture, and waste stream issues. These supporting analyses were incorporated in the concept write-ups or included in their entirety in the appendices.

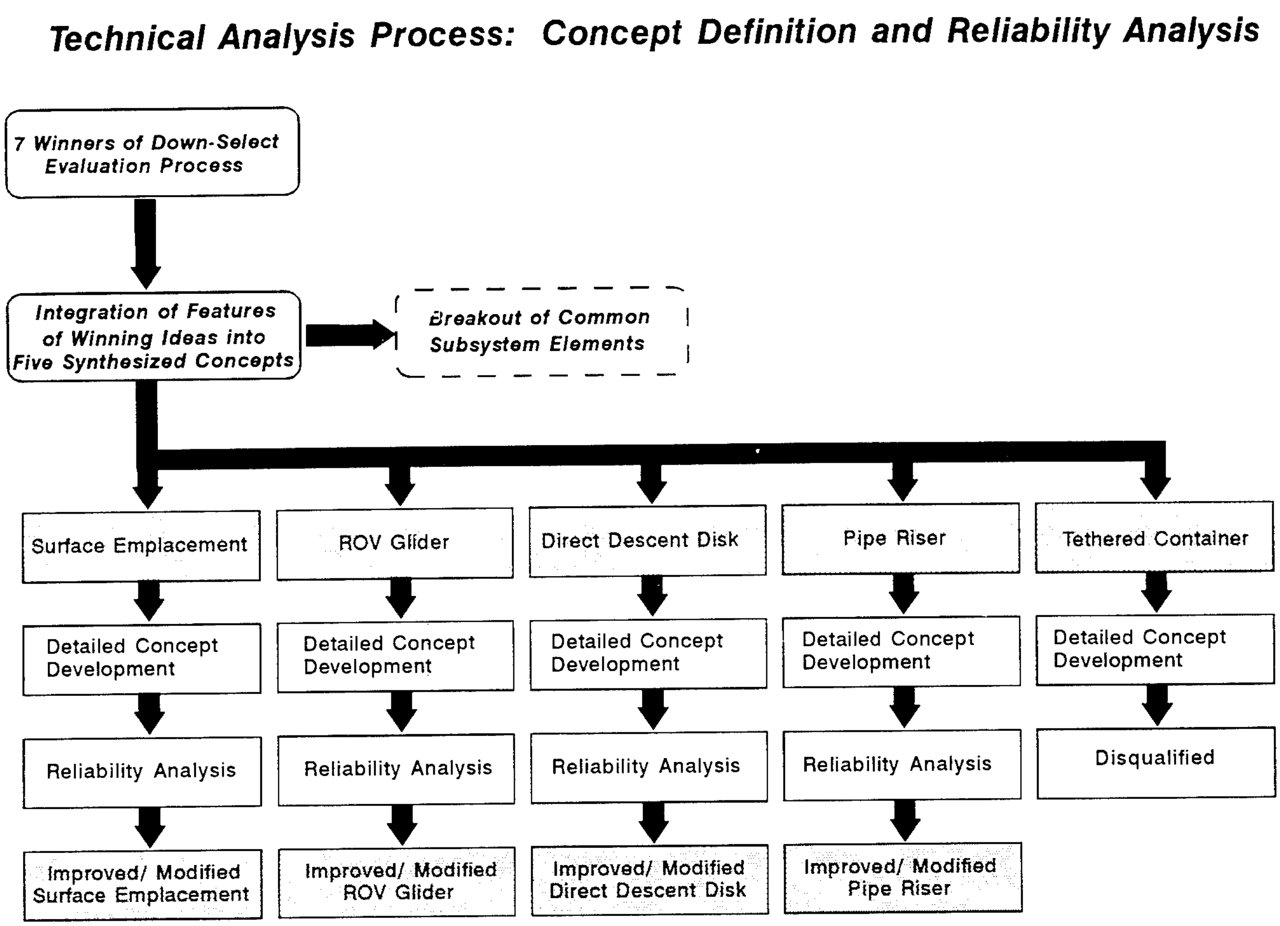


Figure 2.0-2
Technical Analysis Process Flow

3.0 DOWN-SELECTION PROCESS

To select the most realistic and viable APWI concepts, 30 candidate concept patents were evaluated individually in a down-selection process.

OTECH has performed previous studies in deep ocean isolation and has completed, under Internal Research and Development (IRAD) funds, a broad based patent search for ocean isolation concepts. This comprehensive patent search identified 128 ocean isolation technology patents. The patents ranged in complexity from individual pieces of ocean isolation technology to entire isolation systems incorporating many pieces of technology. The patents were dated from 1895 to present. Thirty of these 128 patents were comprehensive summarizing the other 98 as prior art. Appendix A contains a one-page pictorial and summary for each of these 30 patent concepts.

To select the most realistic and viable APWI concepts, the 30 candidate concept patents were evaluated individually in a down-selection process as described in Appendix B. Within the scope of this study, the three major qualitative parameters that must be considered when evaluating an APWI concept are environmental soundness, engineering feasibility, and cost effectiveness. The down selection evaluation examined each concept as a tradeoff between these inseparable parameters. For example, a cost-effective concept is not a good APWI concept if the issues of environmental soundness and engineering feasibility can not be obtained. The concepts must be developed as an interrelation of these environmental, engineering, and cost factors. Initially eight evaluation criteria were developed from each of the three categories for a total of 24 evaluation criteria. By modification and merging, these were narrowed down to 20 criteria. A brief explanation for each of the 20 evaluation criteria follows in Table 3.0-1.

The complete process and results of the down-select including the supporting statistics are contained in Appendix B. The statistics used to pick the "winning" concepts were organized in spreadsheet format to allow verification of statistical methods by others. A potential concern regarding the results of these data was the small number of evaluators which made the possibility of randomness an issue. A confidence level of less than 95% would suggest that the evaluator sample set is too small. As seen in Appendix B, the seven winners had a confidence level of greater than or equal to 95%.

It was determined that seven winning concepts could be identified with scores significantly higher than the rest of the population. Tying for first place at 99.9% confidence were concept numbers 15 and 23, and tying for second place at 99.5% confidence were numbers 17, 12, and 11. Concept number 5 took third place at 97.5% confidence and concept number 30 came in fourth at 95% confidence. A brief summary of each winning concept is listed below. Section 4.0 describes the procedure used to integrate these following seven winning concepts into APWI concepts.

#	Criteria	Definition
1	Bulk Waste Potential Exposure to Water Column	Concept's ability to isolate the material from the intervening water column on its descent to the abyssal seafloor.
2	"In Transit" Bulk Waste Containment Integrity/Stability	Concept's ability to keep waste containerized or keep waste from shifting, leaking or spilling during transit.
3	Bulk Waste "As Deposited" Integrity/Stability	Concept's ability to deposit material in such a manner that mounds will be stable or containers will stay intact.
4	Monitoring Ease via Site/Deposit Footprint	Concept's ability to consistently and discretely deposit material in the intended location where monitoring takes place.
5	Remediation Ease via Bulk Waste Deposit State	Concept's ability to emplace material in discrete mounds or containers allowing remediation to occur.
6	Loading/Unloading Ease	Concept's ability to be loaded with existing loading equipment in a timely manner.
7	Transport Ease	Concept's ability to employ conventional design bulk material transporters.
8	Emplacement Ease	Concept's ability to consistently, rapidly, and accurately emplace material on the abyssal seafloor.
9	Reliability/Maintainability (Availability)	Concept's ability to be available whenever needed.
10	Hazard Potential to Navigation	Concept's port operations, transiting to site, and site operations interference with commercial or recreational navigation.
11	Near Shore/Open Ocean Weatherability (Survivability)	Concept's ability to withstand severe weather without loss of APWI concept.
12	Extrapolation from Current Technology(s) (Performance/Operational Risk)	Concept's similarity to technology being successfully used.
13	Developmental/Demonstration Program Time Duration (Experimental/Validation Risk)	Concept's experimental steps necessary to prove it is safe and effective for real operation.
14	Bulk Waste % solids Range Capability ("As Delivered" to Port/Staging Area)	Concepts's ability to work with waste stream products at varying percentage solids or the need for a certain pretreatment.
15	Transport Cost: Port to Site	Cost of transporting the waste streams to the APWI site including consumables and maintenance.
16	Emplacement Cost: Site to Seafloor	Cost of operating concept at the emplacement site including consumables and maintenance.
17	Monitoring Cost: Waste Stream versus Site/Biota Impact	Cost of monitoring effects of candidate's emplaced waste.
18	Capital Asset Cost: Transport/ Emplacement/Monitoring	Cost of candidate waste handling equipment.
19	Port Facility Cost: Staging/Docking/ Handling	Cost incurred during port-side operations including, docking costs, cost of use of handling system, and utilities.
20	Personnel Cost: Training/Labor Skill Category/Etc.	Cost of training/hiring appropriate skill level for technology, number of employees needed, environmental training.

Table 3.0-1
APWI Concept Evaluation Criteria

- Concept #15 - "Process for Hazardous Waste Containment" This concept entombs hazardous waste barrels with eight inches of seamless plastic. The detailed concept illustration and explanation is shown in Figure 3.0-1.

(15) Patent #4,863,638, 5 Sept, 1989, by Harper, III "Process for Hazardous Waste Containment"

- o Describes a process for hazardous waste containment, using successive entombment features:
  - Metal cylindrical drums, lead-lined if low level radioactive waste, banded together with steel straps in groupings of two to eight, entombed with a plastic casing to prevent leakage.
  - Drums encoded/marked to identify contents.
  - Seamless clear plastic casing applied via a steam heated molding process, at least 8 inches thicker than the outer boundary of the containers.
  - Pallet or casing support means provided to facilitate handling and ensure stability, may be biodegradable in cases or underwater placement.
  - Entombed waste can be used as a "building block" for sea walls; minimizing beach erosion; as support platform for objects placed in water; etc.

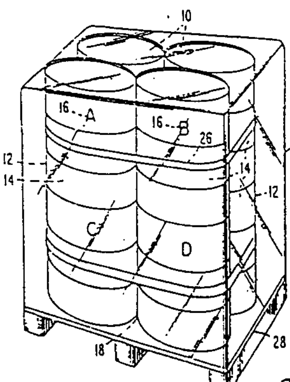


FIG. 1

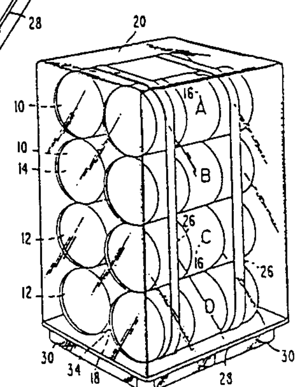


FIG. 2

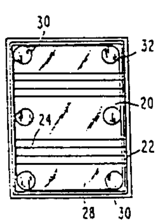


FIG. 3

Figure 3.0-1
Concept #15

- Concept #23 - "Toxic Waste Disposal to an Abyssal Plain" Toxic waste in a flexible bladder is deployed at the surface via trap doors. The detailed concept illustration and definition is shown in Figure 3.0-2.

(23) Patent # GB 2 229 145 A, 19 Sept., 1990, by K.A.K. Eriksen "Toxic Waste Disposal to an Abyssal Plain"

- o Isolates contaminated waste from water column using a flexible container with flaps to reduce to speed of descent, aid in steering to maintain vertical descent.
- o Uses a specially built vessel or tanker to carry a slurry in special chambers sealed on top and open to the sea on the bottom. Each chamber contains a fillable flexible container and a lower trap door. Sea water is allowed to enter chamber during the container filling to minimize induced stresses in the container itself.
  - Once filled, the lower trap doors are tilted open and the containers allowed to slide off and descent to rest position on the ocean floor.

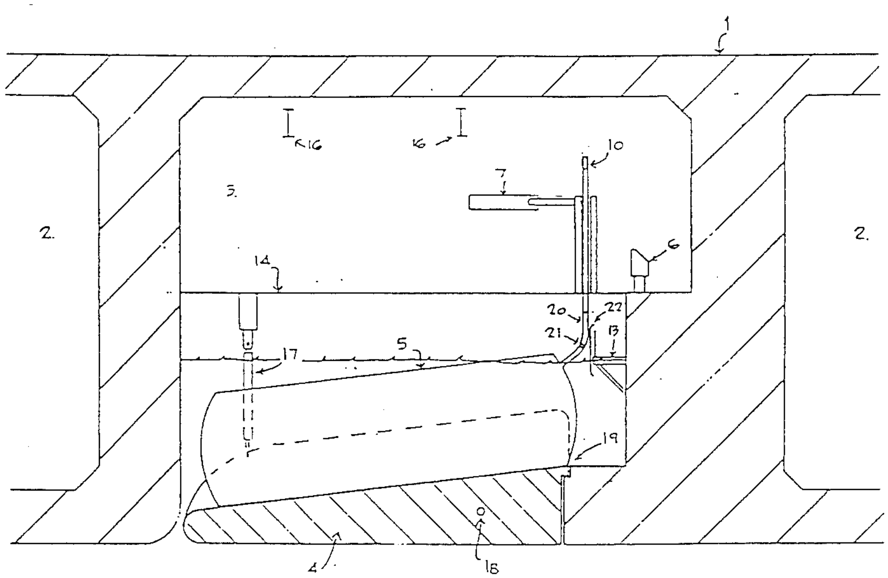


FIG. 4

Figure 3.0-2
Concept #23

- Concept #17 - "Method for the Forming and the Deposition in a Selected Place of a Bulk." Bulk wastes are placed in receptacle with disposable liner material; the contained waste bulk can be released at the surface or lowered to bottom. The detailed concept illustration and definition is shown in Figure 3.0-3.

(17) Patent #4,878,446, 7 Nov., 1989, by J. Vermeulen "Method for the Forming and the Deposition in a Selected Place of a Bulk"

- o Employs an articulated tank/receptacle with insertable/disposable liner (closable bag) for bulk containment.
- o The tank may be opened on the surface or lowered to the desired release depth through several means (cables/straps)
- o Intended for loose or lightly cohesive material such as sand or other ground material, for use as the core or vase or a dam, quay, bank reinforcement, a jetty or a breakwater or for filling holes or trenches in the bed or a waterway.

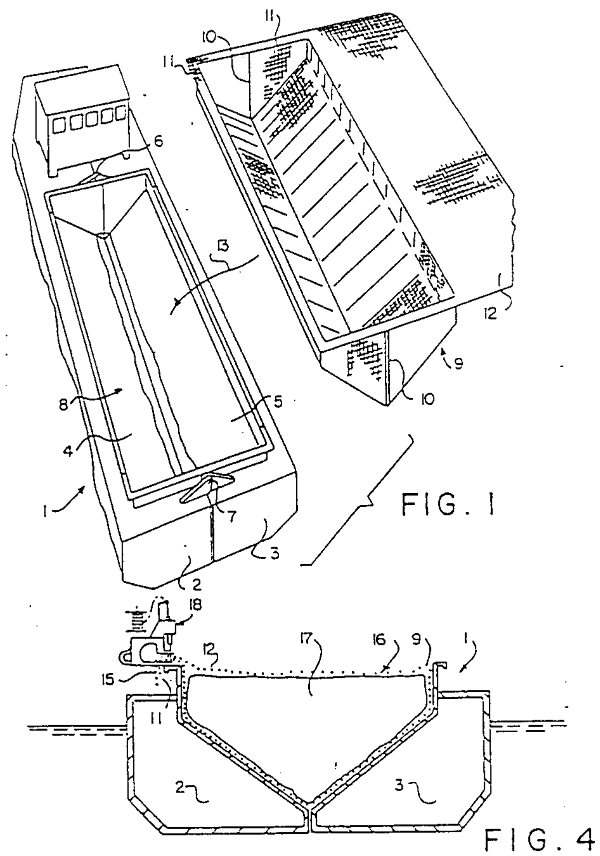


FIG. 1

FIG. 4

Figure 3.0-3
Concept #17

- Concept #12 - "Transportation and Disposal of Waste Material." Container type and shape to allow maximum storage of waste materials during transport. The detailed concept illustration and definition is shown in Figure 3.0-4.

(12) Patent #4,525,100, 25 June, 1985, by Zawadzki, Jr., et al. "Transportation and Disposal of Waste Materials"

- Employs a temporarily shape-competent (box) but excess moisture-vulnerable type container with flexible fluid filled impervious liners.
- Takes advantage of the slump down due to "shake-down" transport from the source to storage facility, caused by liberation of entrained air or absorbed air, to affect similar action between contiguous containers to spread against each other and close any previously existing spaces therebetween.

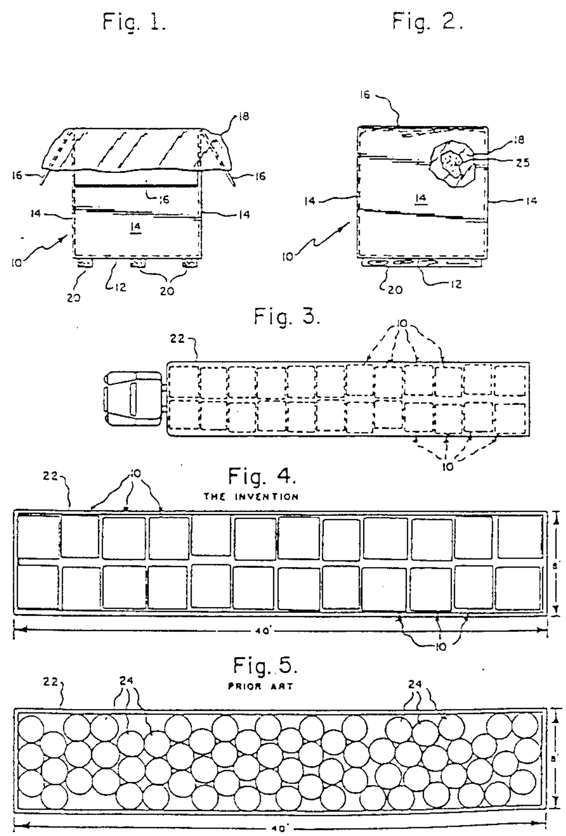
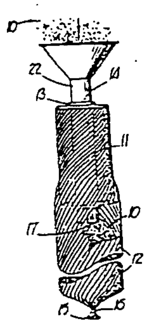


Figure 3.0-4
Concept #12

- Concept #11 - "Method for Chemically Solidifying and Encapsulating Hazardous Wastes in One Continuous Operation." Polyethylene membrane resembling a sausage link is filled with a semi-liquid waste and an additive to solidify. The detailed concept illustration and definition is shown in Figure 3.0-5.

(11) Patent #4,518,507, 21 May, 1985, by Conner "Method for Chemically Solidifying and Encapsulating Hazardous Wastes in One Continuous Operation"

- o Employs an approximately 1 ft. diameter polyethylene membrane to form "sausage link" increments or solidified sewage sludge or similar liquid or semi-liquid waste.
- o Uses a water reactive solidification agent, a dry water absorbent material and a powdered alkali metal silicate to convert the admixture into a chemically and physically stable end product containing virtually no water.
- o Permits the encapsulated waste to harden in-situ, setting into a sedentary mass, and prepared for ultimate disposal in landfills, ocean relocation sites and the like.



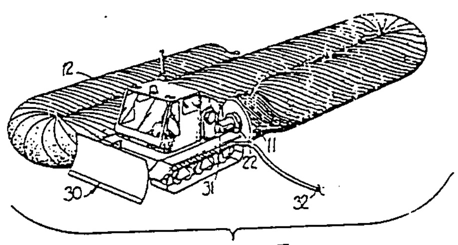


FIG 5

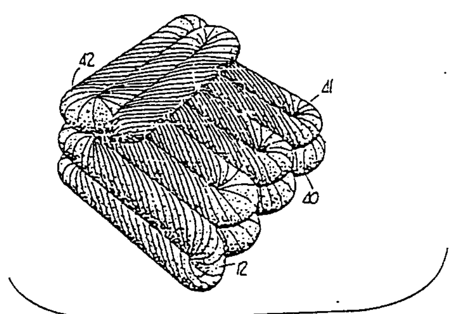


FIG 6

Figure 3.0-5
Concept #11

- Concept #5 - "Submersible Barge Retrievable Storage and Permanent Disposal System for Radioactive Waste." Tethered concrete sinkable/retrievable barge containing waste. Detailed concept illustration and definition is shown in Figure 3.0-6.

(5) Patent #4,305,679, 21 Dec., 1979, by F.L. Goldsberry "Submersible Barge Retrievable Storage & Permanent Disposal System for Radioactive Waste"

- Triple-redundancy concrete cell containment system, sealed, actively vented when on the surface, passive convection when on the seabed.
- Employs a "submarine control device" for both lowering and retrieving the barge (no specific details provided).

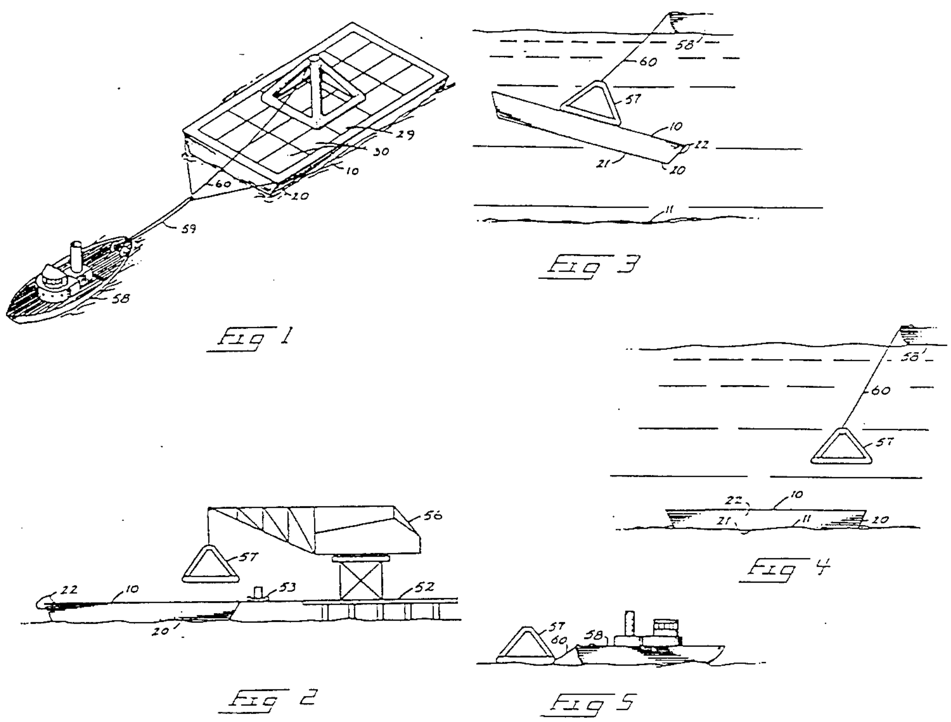


Figure 3.0-6
Concept #5

- Concept #30 - "Transportation and Discharge of Waste to Abyssal Depths" Patent contains two independent concepts; ROV Glider and Quad Riser. ROV Glider is a controllable vehicle that is towed to isolation site, released, descends to designated site, empties load, and ascends to surface. Quad Riser is a set of four lines of pipe descending vertically to near the seafloor for emplacement of waste. Detailed illustrations and definitions are shown in Figure 3.0-7.

(30) Patent # (Pending), 22 Sept., 1993, W.R. Richards et al. "Transportation and Discharge of Waste to Abyssal Depths"

- ○ Employs either a 50,000 DWT barge/ ROV Glider, or a Quad Riser Assembly consisting of four 54 inch diameter plastic (neutrally buoyant) lines for emplacement of waste. Permits very large tonnage/hr to be deposited with minimal disturbance to the sea bed, thermally habituated and adaptable to handling either loose bulk, or "containerized" bulk.
- ○ For the quad riser, thermal habituation is achieved via 'OTEC' analogy, wherein water required for generation of the slurry is retrieved from depths > 3000m. This minimizes transport of nutrient-rich surface waters to abyssal depths, as well as assuring thermal habituation.
  - The ROV Glider uses free-flood "space-frame" cargo bays for bulk transport from the port to the disposal site, thereby permitting maximum bulk surface area to be exposed to seawater.
- ○ The ROV Glider is tower to the disposal site at a depth of > 300ft and < 1000ft. prior to release above the disposal site. It is flooded negative and follows a descending spiral glidepath to the designated site, releases its bulk cargo, and due to positive buoyancy of the empty glider, reascends to the surface.
- ○ The quad riser requires the use of bulk transport vessels to ferry the bulk waste from the port to the disposal site.

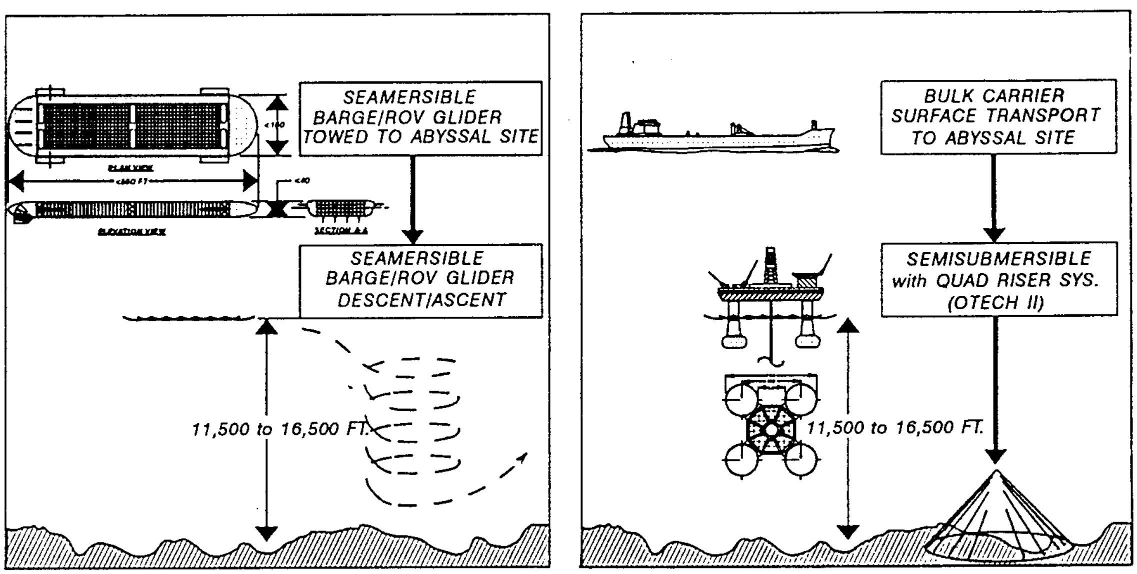


Figure 3.0-7
Concept #30

4.0 SYNTHESIS

Combining similar technologies of the seven winning APWI concepts from the down-selection, five APWI concepts could be envisioned; these are Surface Emplacement, ROV Glider, Direct Descent Disk, Pipe Riser, and a Tethered Container.

Although the seven winning concepts identified in Section 3.0 provide good methods for the general concept of ocean isolation, it became apparent that fine tuning or synthesis would have to occur in order for them to comply with the System Level Requirements identified for APWI. The synthesis process examined one concept at a time applying the system level requirements to conform the general concepts to APWI concepts and identify other issues that would require research.

- Candidate #15 (Figure 3.0-1) was the first to be examined. By examining environmental regulations, it was found that the APWI wastes had no regulations dictating packaging, such as the lead-lined barrels or complete entombment shown in this concept. Considering the annual volume of waste expected to be handled by a single APWI port (Section 5.6-1), this concept would be astronomical in cost. By changing the concept to a lower cost packaging material that would still prevent waste loss in the intervening water column, this type concept would be feasible for APWI.

- Candidate #23 (Figure 3.0-2) employed a flexible bladder that would be a cost effective acceptable container to isolate the waste from the intervening water column. These flexible bags are available in various sizes, types of material, and fabric construction.

- Candidate #17 (Figure 3.0-3) is a larger scale approach using flexible bags to isolate waste from the water column. The concept states that the bags may either be released from the surface or lowered by cables. This lowering of waste to the seafloor is attractive because it seemingly gives positive control of emplacement.

- Candidate #12 (Figure 3.0-4) is a general idea of maximization of storage space when transporting a bulk. This concept is applicable to any APWI concept envisioned. Because of the large amount of waste to be transported to APWI sites along with the large transiting distances to these isolation sites, maximization of space will be an issue no matter which concept is examined.

- Candidate #11 (Figure 3.0-5) employs a tether to lower a large container of waste to the seafloor. This concept shows a "physical connection" between the surface and the seafloor. This control would allow for accurate placement and the ability to retrieve the waste if necessary. The near-vertical descent of the container allows for accurate targeting of the disposal area.

- Candidate #30 (Figure 3.0-6) shows two approaches to bridge the distance between the surface and the abyssal seafloor. The ROV Glider approach descends in a predictable path to release its contents just above the seafloor and ascends to the surface. The Quad Riser assembly employs a vertical pipe to physically bridge the water column from ocean surface to sea floor. Waste travels down the pipes and is discharged near the seafloor.

From the examination of these seven winning concepts, the following groupings became apparent that would isolate the waste from the water column and emplace it within a 500 m X 500 m target area:

- A container was used to isolate the waste from the water column (with or without a tethered connection with the surface). This grouping was split into two separate concepts: a surface emplacement concept where the container free-falls to the seafloor and a tethered container that is winched from the surface to near the seafloor.

- A submersible vehicle was used to isolate the waste from the water column. This grouping was split into two separate concepts: a ROV Glider that has a predictable spiral glidepath, and an inherently hydrodynamically stable disk which has a near vertical glidepath mimicking the descent of a tethered container.

- A pipe was used to isolate the waste from the water column.

The results of this synthesis identified five concepts which were derived from the winning concepts from the down-select process. These concepts are:

1. Surface Emplacement - Bagged waste is released from the surface and allowed to free fall to the seabed. A required assumption for this concept is that, with currents and bag shape known, it is possible to predict the landing location of the container on the seabed within a 500 x 500 meter area.

2. ROV Glider - Controlled descent of a submersible glider to near the seafloor. The bagged waste is released and falls to seafloor. The glider then buoyant, returns to the surface.

3. Direct Descent Disk - Direct autonomous vertical descent of a disk to near the seafloor. The disk brakes and the bagged waste is released and falls to the seafloor. The disk, then buoyant, returns to the surface.

4. Pipe Riser - Set of large diameter pipes running vertically from the sea surface to near the seafloor. Two pipes bring water up from 700 m depth to dilute slurryized waste. Dilution is critical to achieve a low bulk specific gravity for the slurry, such that the resultant static head on the discharge riser is sufficiently large to generate the required gravity flow volume. Dilution with the colder water from 700 m depth also greatly reduces the potential for a thermal plume. Further, using the deep water versus surface water, additional oxygen and dissolved carbon are not added to the isolation site above that in the waste. The slurryized waste travels down two pipes isolating it from the water column and is discharged near the seafloor.

5. Tethered Submersible Container - Large loads of waste are winched from the surface to be released near the seafloor. The container is sealed to eliminate contact of the waste with the water column. The bottom of the container opens near the seafloor expelling the waste payload.

Each of these concepts was utilized as the basis or starting point for detailed conceptual design. In the initial examination of the winning concepts and the synthesis process, certain elements were present and basically identical between the concepts. These common elements are:

- Transporter System - Taking into consideration the transiting distances, waste stream volumes, and minimum transiting speeds identified in the System Requirements Report, selection of the optimum transporter size and type was made.

- Handling Systems - Given the volume and physical state of the waste streams entering the port, the size and type of handling system needed to load the APWI vessel was determined.

- Waste Stream Containers - Based on the needs of each concept, the ideal material, size, and shape of containers was defined.

- Docking Space - Given the port locations identified in the System Requirements Report, and the size of the transporter chosen for the APWI concepts, existing docking spaces and associated equipment for the APWI concept were identified.

- Interface of APWI System with Waste Streams - Taking into consideration the generation method and normal preprocessing steps for the three waste streams (dredged material, sewage sludge, and municipal incinerator fly ash), the physical state (percentage solids and specific gravity) of the waste when the APWI System receives them was determined.

- Isolation Site Capacity - Storage capacity in a 500 m X 500 m isolation site based on predicted mound geometry was calculated.

5.0 CONCEPT DEFINITIONS

The five concepts identified in the synthesis process (Surface Emplacement, ROV Glider, Direct Descent Disk, Pipe Riser, and Tethered Container) have undergone an engineering assessment to examine their viability for APWI.

The five APWI concepts are described in the following sections. Each section provides a concept description, operational description, summary of advantages and disadvantages, a discussion of key technical issues, and a manufacturability/producibility assessment.

Each concept is focused upon a specific method for achieving reliable emplacement of large tonnage increments of waste (Contaminated Dredged Material, Sewage Sludge, and Municipal Incinerator Fly Ash) into designated APWI sites. This waste is delivered by transport vessels operating from various coastal ports to designated APWI sites located in the Atlantic, Gulf of Mexico, and the Pacific, all within 1850 km (1000 nmi) of the various ports. These designated isolation sites, approximately 10 km x 10 km, consist of up to 400 local sites approximately 500 m x 500 m. The 500 m X 500 m isolation site will facilitate the ability to achieve both reliable and effective monitoring of the site's chemical, biological and physical state.

The engineering assessment of various methods for achieving emplacement of large tonnages of waste, without waste loss to the intervening water column, resulted in the selection of five potential concepts. This process was previously described in Sections 3.0 and 4.0. The following sections provide a detailed concept description of each of the concepts:

- Surface Emplacement: Section 5.1
- ROV Glider: Section 5.2
- Direct Descent Disk: Section 5.3
- Pipe Riser: Section 5.4
- Tethered Container: Section 5.5

The engineering assessment is continued in Section 5.6 which provides a summary level description of the common elements. These common elements consist of the transporter system, handling system, waste stream containers, docking space, interface of APWI concepts with waste streams, and isolation site capacity.

The engineering assessment is concluded in Section 6.0 with a Reliability Evaluation in Section 6.0 which consists of both a Fault Tree evaluation of "undesired events" versus potential causal mechanisms, and a Failure Modes, Effects, and Criticality Analysis (FMECA) to assess means to mitigate the potential failure mode. Based upon the evaluation in this section, an overall comparison is made of technical risk between the concepts. An assessment of "high" technical risk may be interpreted in two ways: (1) it identifies the need for the incorporation of additional redundant elements, which would result in adding to the degree of complexity, and therefore impact associated costs; and (2) it identifies a critical area, which requires further detailed investigation, or experimental validation before conceptual feasibility can be demonstrated. Based upon the above assessment, all concepts have been revised as required to provide the essential redundancy for the identified critical area(s) subsystem elements. The comparison of these concepts to System Level Requirements is found in Section 7.0. Critical area(s) of each of the concepts which require further detailed investigation or experimental validation are discussed in Section 8.0.

5.1 SURFACE EMPLACEMENT

5.1.1 SURFACE EMPLACEMENT CONCEPT DESCRIPTION

The Surface Emplacement concept is illustrated in Figure 5.1.1-1, with an overall concept process flow diagram illustrated in Figure 5.1.1-2. The transporter illustrated in Figure 5.1.1-1 may be either a self-powered bulk carrier with trap-doors, or an Integrated Tug/Barge (ITB) with trap doors, with nominal 25,000 DWT cargo capacity. Individual cargo bays in a hold arrangement consisting of a 17 X 3 array, and approximately 9.1 m (30 ft) X 9.1 m (30 ft) X 6.1 m (20 ft) deep, would yield a maximum cargo volume capacity of 26,000 m^3 (34,000 yd^3). These cargo bays would be lined with a flexible bag of 510 m^3 (670 yd^3) capacity, and filled to approximately 75% capacity 380 m^3 (500 yd^3). Wet filling (cargo bays free-flooded) is desired to minimize stresses on the bag during filling. Use of the disposable bags assures that the bulk waste is isolated from the intervening water column during the free-fall descent from the surface to the designated APWI site location. The following discussion incorporates results of an independent technical evaluation of transporter issues, performed by John J. McMullen Associates, Inc. (JJMA), Naval Architects (see Hightower et al. 1994, Attachment 1, "Surface Emplacement Vessel Tradeoff Issues").

The principal dimensions and displacement for the vessel are derived from a cargo bay with a 17 X 3 rectangular cell array, with length of bow and stern derived to give a typical low-speed hull form. The draft is derived from a 6.1 m (20 ft) cell load depth, with an additional 1.2 m (4 ft) allowance for trap door structures. A hull depth of 12.8 m (42 ft) was selected to avoid "special consideration" under ABS Rules for Building and Classing Steel Vessels. For a 25,000 DWT self-powered bulk carrier, major characteristics are as follows:

- Length Overall (OA) of 214 m (700 ft); Length at Water Line (WL) of 207 m (680 ft); Beam of 32 m (106 ft); Draft of 7.3 m (24 ft); Depth of 12.8 m (42 ft); & Displacement of 39,000 metric tons (megagrams or Mg).

The estimated displacement of 39,000 Mg at full load is summarized as follows:

■ Cargo Deadweight	25,000
■ Residual Seawater in Cells	2,000
■ Fuel	350
■ Lube Oil	5
■ Stores	5
■ Potable Water	50
■ Crew & Effects	5
■ Light Ship	11,585
Full Load Displacement	39,000

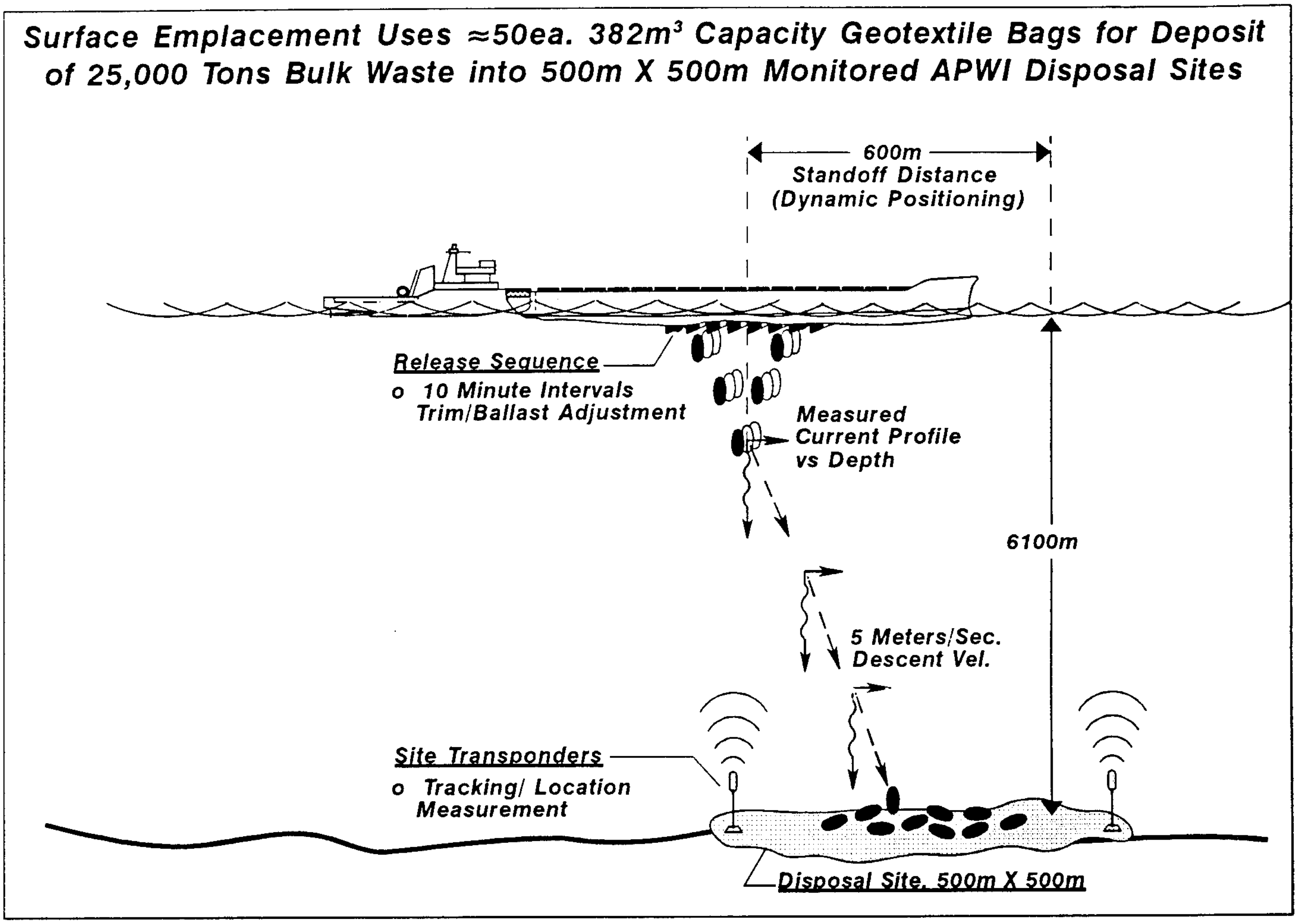


Figure 5.1.1-1
Surface Emplacement

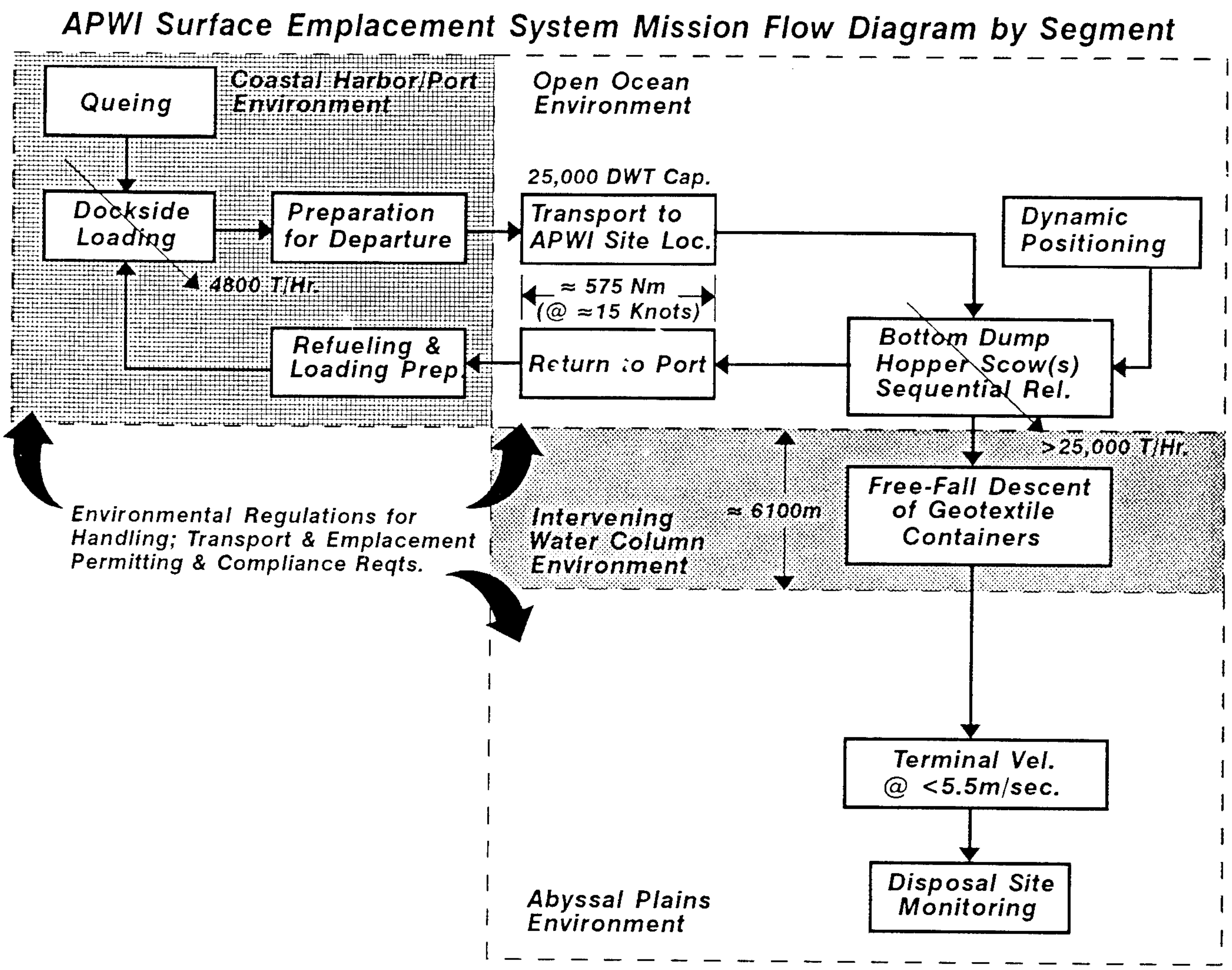


Figure 5.1.1-2
Surface Emplacement Process Flow Diagram

The Light Ship weight may be subdivided into (Mg):

■ Steel Weight	8,300
■ Machinery	2,100
■ Outfit	1,000
■ Hull Doors	200
Light Ship Weight	11,600

The steel weight is based upon tanker data. The machinery weight is based on twin screw propulsion, with 6700 kW (9000 bhp) per shaft, and three 500 kW ship service generators (one in standby at all times). A twin screw plant was selected because of the limited draft, maneuvering and plant reliability considerations. The estimated required horsepower for 7.71 m/s (15 knot) transit speed is 10,500 kW (14,100 bhp). To sustain this speed the installed MCR (Maximum Continuous Rating) is 13,100 kW (17,600 bhp) provided by two 6700 kW (9000 bhp) medium speed geared diesels.

The vessel transverse stability and draft change during cargo release is based upon a waterplane area of 6690 m^2 (65,600 ft^2), a waterplane inertia of 482,000 m^4 (55,900,000 ft^4) less that of the free-flood cargo bays of 267,000 m^4 (31,000,000 ft^4), and a total volume for 39,000 Mg displacement of 38,200 m^3 (1,365,000 ft^3), yielding a distance between the metacenter and the center of buoyancy (BM) of 5.56 m (18.2 ft). The center of buoyancy is taken at 52% of draft, or 3.8 m (12.5 ft) above base, yielding a metacenter at 9.36 m (30.7 ft) above base. As Vertical Center of Gravity (VCG) for the fully loaded vessel is estimated at 5.7 m (18.7 ft), the corresponding metacentric height (GM) would be 3.66 m (12.0 ft).

In order to provide compensation for the release of the cargo, water ballast must be added to maintain acceptable trim and propeller immersion. Sufficient ballast volume is available in tanks in the wingwalls and ends of the vessel. Uncompensated, the draft change due to cargo release is approximately 2.8 m (9.1 ft). To minimize such rapid and drastic change in draft and trim, a self-powered bulk carrier should not employ a "one-shot" release of the entire cargo, but should provide means to sequentially release portions of the cargo while simultaneously ballasting as required.

The ITB variant possesses two technical advantages over that of the self-propelled bulk carrier. The first advantage is significantly reduced sensitivity to changes in draft. The second advantage is a major reduction to the requirements for ballast tankage, pumps, and piping systems on the barge. The barge could be permitted to operate at 7.3 m (24 ft) draft full load, and about 3.7 m (12 ft) in ballast, with both conditions at essentially level trim. The tug would accommodate the change by reconnecting lower in the notch when in ballast. Several commercially available ITB integration systems are in use which permit a large variation in barge draft. These include hydraulically loaded friction plates on the port and starboard bows of the tug, engaging with reinforced structures on the inner surfaces of the notch. Several examples of these positive engagement articulated systems are ARTUBAR, ARTICOUPLE, Sea-Link and FLEXOR. Depending upon the rate of cargo release, it would be possible to have the tug remain in the notch during the emplacement operation. This is highly desired to mitigate difficulties of re-engagement in the required wind and sea environment.

The ITB variant also possesses two operational advantages over that of the self-propelled bulk carrier. The first advantage is in "barge-swapping", wherein the propulsion plant and crew (the tug) performs transiting/ emplacement operations, while concurrently a second barge is being loaded in port, with swapping of the barges occurring upon return to port. The second advantage involves the potential use of lower powered tugs for a coastal operation "feeder system", with the more powerful tug being used for the ocean-going phase. The feeder tug, because of the high fraction of port time implied by multiple stops, puts less of a premium on speed.

Finally, the ITB variant may possess both regulatory and manning issue advantages over that of the self-propelled bulk carrier. Regulatory issues include stability requirements, fire and bilge pump requirements, and other safety appliance requirements. Manning issues relate to the number and function of specialized personnel and their regulatory status for the purpose of application of SOLAS and 46CFR requirements.

In summary, an ITB is the desired choice for the Surface Emplacement transporter. Light ship weight would be approximately 3000 Mg less than the self-propelled carrier, with an estimated 10% reduction in steel weight and elimination of machinery. The tug for the ITB would probably be custom designed for this application, similar in size to the Kalvik, Maersk Mariner, or Normand Draupne, approximately 1860-2500 DWT. The tug would require approximately 5 to 10% additional shaft horsepower than the self-powered bulk carrier, or approximately 7460 kW (10,000 bhp) per shaft.

5.1.2 SURFACE EMPLACEMENT OPERATIONAL DESCRIPTION

Release of the bagged waste at the isolation site location would occur with the following scenario of operation:

- The transporter arrives on-site, identified by an on-board navigation/global positioning system, and dynamically positions to a predefined standoff distance for release of the bagged waste. The standoff distance adjusts for bag lateral drift during free-fall. This standoff distance is based upon previously established or real-time knowledge of current conditions existing throughout the water column. The free-fall descent terminal velocity is approximately 5.0 m/s, based upon the following assumptions.

  The bag terminal velocity can be estimated using the following equation, where the drag force equals the bag weight in seawater, or Drag = Velocity^2 [C_f (Area, Wetted) + C_D (Area Projected)].

  The terminal velocities, tabulated in Table 5.1.2-1, are based upon a value of C_f of approximately 0.004 (for a velocity range of 10 to 40 ft/s with a size of 6 to 24 ft in diameter), a value of C_D of approximately 1.16, and an overall effective length of 24.0 ft. The value for C_f is derived from a Reynolds Number range from 4.3×10^6 to 51.5×10^6, assuming a seawater kinematic viscosity of 1.4×10^{-5} ft^2/s. The values for C_f could vary from 0.0053 to 0.0033 per Figure 2-28, *Handbook of Ocean and Underwater Engineering*, Myers, Holm, and McAllister, 1969, and values for C_D (Figure 2-24) could vary from 1.11 to 1.28, depending upon whether we assume a circular or a square frontal area. The bag shape is "somewhere" in between. The bulk waste, contained within the bag has an approximate specific gravity of 1.25. Inspection of the equation indicates that a 20% variation in either bag weight in seawater, the value of C_D, or in the value for the projected area, would change the calculated terminal velocity by 10%.

Effective Diameter	Wetted Surface Area	Projected Surface Area	Weight in Seawater	Terminal Velocity
6.0 ft	452 ft^2	28.3 ft^2	9305 lb	17.1 ft/s
12.0 ft	904 ft^2	113.0 ft^2	37,154 lb	17.1 ft/s
24.0 ft	1808 ft^2	452.0 ft^2	148,618 lb	17.1 ft/s

Table 5.1.2-1
Geotextile Bag Terminal Velocity

For an abyssal seafloor site located at 6100 m depth and a standoff distance of approximately 600 m to correct for drift due to an "average" current at the site of approximately 0.5 m/s, the expected emplacement watch circle from a single cell would be 50 m in diameter. This calculation is based on the drift range of bags falling at +/- 10% of the nominal terminal velocity, 4.5 m/s and 5.5 m/s. The cells would span a distance of approximately 160 m, and assuming that the vessel maintains station-keeping standoff distance, the minimum emplacement watch circle would be a 210 m diameter target area. Physical modelling is required to accurately determine bag drift variability in order to determine if this watch circle is realistically achievable.

- The transporter interrogates previously deployed and located bottom transponders to confirm its relative position with respect to the site and the status of the bottom transponders in the site range. A deployable transponder is released, having a nominal terminal velocity of approximately 5 m/s. The transporter confirms that the transponder has landed within the targeted area, confirming that the desired standoff distance has been achieved. If not, adjustment is made to the vessel's relative position and a second transponder is released. The required time for the first (and any subsequent trial) is less than 25 minutes (min) before commencement of the next step.

- The transporter commences emplacement operations, opening the hull trap doors in the following sequence to minimize vessel trim impact:
  - Row #9 (Midship)
  - Rows #8 & #10
  - Rows #7 & #11
  - Rows #6 & #12
  - Rows #5 & #13
  - Rows #4 & #14
  - Rows #3 & #15
  - Rows #2 & #16
  - Rows #1 & #17 (Forward and Aft locations)

  Since the ITB configuration is relatively insensitive to ballasting, sequential release of the rows could occur at approximately one minute intervals limiting time on-site to less than 0.5 hour (hr) for emplacement (excludes initial transponder release/target verification time). Note that a self-propelled configuration might require a longer interval between successive release(s) to account for required ballasting operations to maintain trim and propeller immersion. The operational timeline for surface emplacement is shown in Figure 5.1.2-1.

  Each row, with the exception of Row #9, would be fitted with a transponder operating on a unique frequency and monitored using equipment similar to the Benthos DS-7000-16 Acoustic Signal Processing Deckset. The transponders would operate in a useable frequency range of 7 to 15 kHz, on 250 Hz increments, and matched to a high performance hull mounted transducer for deep water applications. The Deckset interrogates each row of waste bags as it nears the seafloor and tracks it to its landing point. This position is logged by vessel personnel and maintained in permanent record-keeping form to comply with permitting requirements. The bagged waste survives landing at less than 5.5 m/s (18 ft/s) without rupturing the bag, based upon the U.S. Army Corps of Engineers (COE) testing of geotextile bags of similar size and weight at the same landing velocities. Hightower et al. (1994), Attachment 2, "Dredged Material Filled Geotextile Containers," provides additional detail. In addition, the use of disposable, low cost bags is described further in Section 5.6. The use of throw-away, low cost, battery-powered transponders facilitate the Surface Emplacement concept's necessary monitoring and compliance requirements for operation and use of the isolation site.

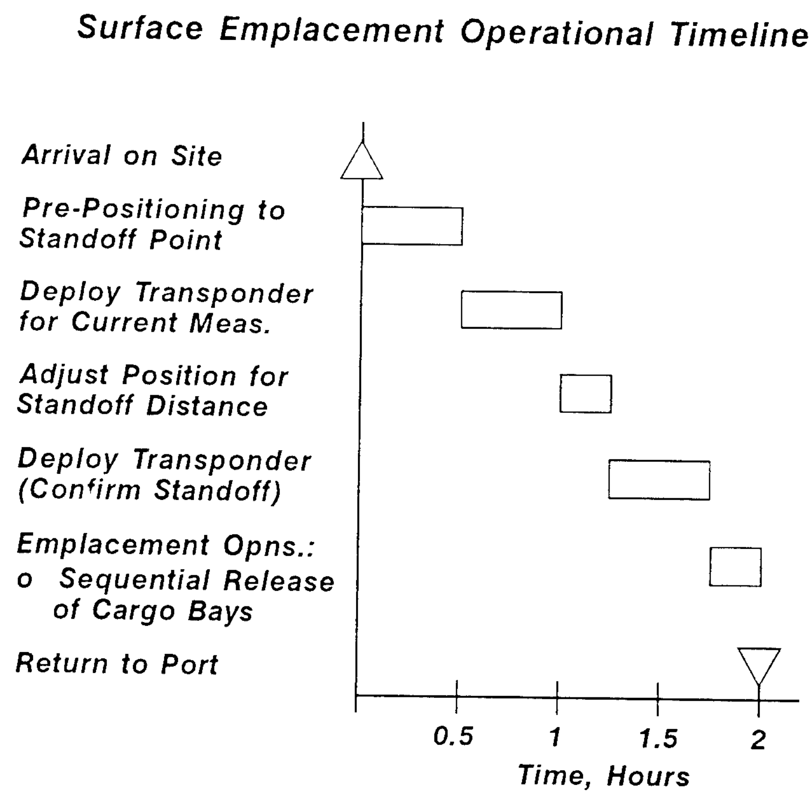


Figure 5.1.2-1
Surface Emplacement Operational Timeline

5.1.3 SURFACE EMPLACEMENT SUMMARY OF ADVANTAGES AND DISADVANTAGES

Surface Emplacement offers the simplest solution to the achievement of a reliable method for the emplacement of bagged bulk waste into designated APWI sites. Additionally, by use of the ITB, it is capable of emplacing its entire load within one hour after setup. Finally, solutions already exist in conventional naval architectural practice to implement the desired vessel configuration. No new technology fabrication methods or practices are required for its implementation. The disadvantages are as follows:

- The watch circle for the emplaced bagged waste will have inherently large dimensions versus that of the local isolation site dimensions (approximately 50%), with expected random scattering of individual bags due to unforeseen variation in currents, loaded bag weights, and shape of individual bags in free-fall descent (approximately 25 min) through the water column.

- The required standoff distance from the isolation site position is determined from knowledge of the actual current conditions existing at various depths in the water column and the terminal velocity of the individual bags. The waste stream products, Dredged Material, Sewage Sludge, and Municipal Incinerator Fly Ash,

all possess different bulk specific gravities, or weight in seawater. This necessitates different standoff distances for each type waste. Additionally, the lower the waste product bulk specific gravity, the greater the standoff distance required to account for the slower time of descent, and subsequent longer trajectory to the emplacement site. If the descent time were increased by a factor of two, the expected random scattering could approximate that of the local site dimensions itself. Under this condition, the statistical probability of bagged waste packages falling outside the designated site location would be greater than 0.95, with 33% of the 51 packages outside of the monitored area.

5.1.4 SURFACE EMPLACEMENT KEY TECHNICAL ISSUES

- **Bag Hydrodynamics:**

The fundamental technical issue to be addressed for Surface Emplacement is the hydrodynamic performance characterization of approximately 380 m^3 (500 yd^3) of bagged waste with varying weight in free-fall descent through a water column of up to 6100 m. Previous experience by the COE is only applicable to water depth of approximately 90 m, or less than 5% of the APWI requirement. Empirical testing will be required to quantify boundary condition constraints on variation in bag weight versus the measured watch circle scatter pattern, as would exist for the disposal site currents, and to assess bag susceptibility to lateral drift (or side-slip) due to variations in hydrodynamic shape and asymmetric distributions of mass within the bags.

- **Bag Survivability:**

Bag survivability upon seafloor landing will have to be determined for deep water emplacement. This includes the design of bag seams, any expansion joints, and the filler nozzle.

- **Cargo Bay/Trap Door Design:**

Testing of similar types of geotextile bags conducted by the COE (Hightower et al. 1994, Attachment 2) has shown that the highest stresses on the bags occur during release from the barge. This stress point occurs as the bag squeezes out of the opening made by the split hull barge hopper doors as they slowly open. The conclusion is that the trap door/bag release mechanism for the surface emplacement concept must be carefully designed to avoid stressing the bag as it exits the cargo bay.

In addition, the cargo bays should be designed with low-friction side wall surfaces to facilitate rapid egress of the bags. The size and shape of the cargo bays will determine the initial shape of the bag, and therefore the bag hydrodynamics. The bag hydrodynamics and the cargo bay design are directly coupled and will have to be analyzed together.

- **"Throw-away" Transponders:**

Battery powered/multiple channel transponders will be required to assure that the bags are emplaced within the desired disposal site monitoring area. The host platform must be capable of interrogation of a set of seafloor mounted transponder repeaters to determine the final location of individual groups of bags released from the surface. The "throw-away" transponders must provide short range (<500 m) signal strength capability to assure that the repeaters may register their arrival at the site location. Capability currently exists to provide up to 16 channels for interrogation of individual groups of bags. The proposed design approach, described in detail in Hightower et al. (1994), Attachment 4, provides the desired capability for a low cost, "throw-away" unit.

- **Geotextile Bags:**

  Geotextile bags are presently being manufactured by two vendors in the U.S., with annual production volume for 380 m^3 (500 yd^3) capacity bags presently at 700 per year. The Surface Emplacement concept would require approximately 4900 ea., 510 m^3 (667 yd^3) capacity bags per year, or 7 times the current annual production rate. Discussions with the existing vendors, and other potential suppliers of similar product, are required to assure capability to meet revised form factor(s) and to realize the lowest overall production cost.

5.1.5 SURFACE EMPLACEMENT MANUFACTURABILITY/ PRODUCIBILITY ASSESSMENT

All material elements of the Surface Emplacement concept are well understood, including the use of a conventional ITB variant, bag selection and use of transponder tracking/location. Associated costs are comparable, by direct extrapolation, to current practices for development of similar transport systems.

5.2 ROV GLIDER

5.2.1 ROV GLIDER CONCEPT DESCRIPTION

The ROV Glider concept is illustrated in Figure 5.2.1-1. The overall operational scenario diagram is illustrated in Figure 5.2.1-2. The transporter illustrated in Figure 5.2.1-1 will be an Integrated Tug/Barge (ITB) with a 25,000 DWT cargo capacity. The waste cargo is contained in hexagonal cells forming a honeycomb of 153 cells arranged in six rows of alternating 26 and 25 cells per row. These cargo bays are lined with the same geotextile liner as suggested for the surface emplacement concept (Section 5.1) and are filled to about 75% of capacity. Use of these bags will prevent waste loss in the intervening water column as the glider descends to the APWI site.

Initial size and displacement of the ROV Glider is based upon a 153 hexagonal cell cargo array, having dimensions of 108 m (354 ft) in length, and a beam of 30 m (98.5 ft). Hull length is increased by adding a 15 m tapered tail section to improve vortex shedding and a 7.5 m rounded bow section to improve hydrodynamics. The following discussion incorporates results of an independent technical evaluation of glider issues provided by JJMA (see Hightower et al. 1994, Attachment 3, "Underwater Glider Tradeoff Issues").

For a 25,000 DWT ROV Glider configuration, major characteristics are as follows:

- Length OA of 130 m (426 ft); Length WL of 129 m (423 ft); Beam of 30 m (98.5 ft); Draft (Unloaded) of 7.0 m (23.0 ft); Depth of 10 m (32.8 ft) and Displacement of 29,000 Mg.

The estimated displacement of 29,000 Mg at full load is summarized as follows:

■ Cargo Deadweight	25,000
■ Cell Array	
• Hexcell Structure	2,000
• Syntactic Foam	1,360
• Interior Cell Wall	200
• External Vehicle Skin	150
■ Hull Structure	
• Forward/Aft Fairings	120
• Upper Trap Doors	150
• Lower Trap Doors	300
• Syntactic Foam	300
■ Machinery	
• Electrical	25
• Hydraulic	75
Full Load Displacement	29,000

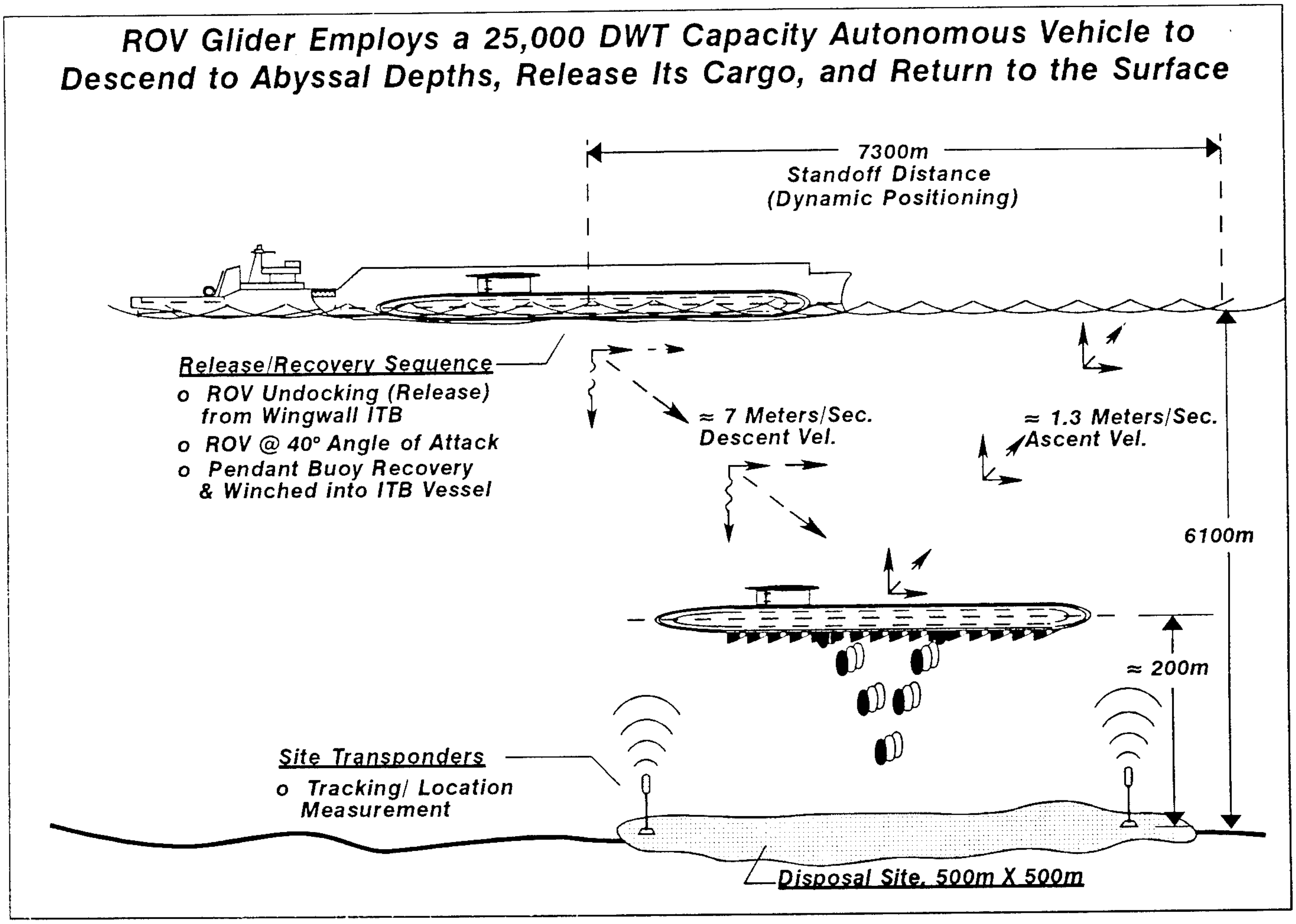


Figure 5.2.1-1
ROV Glider

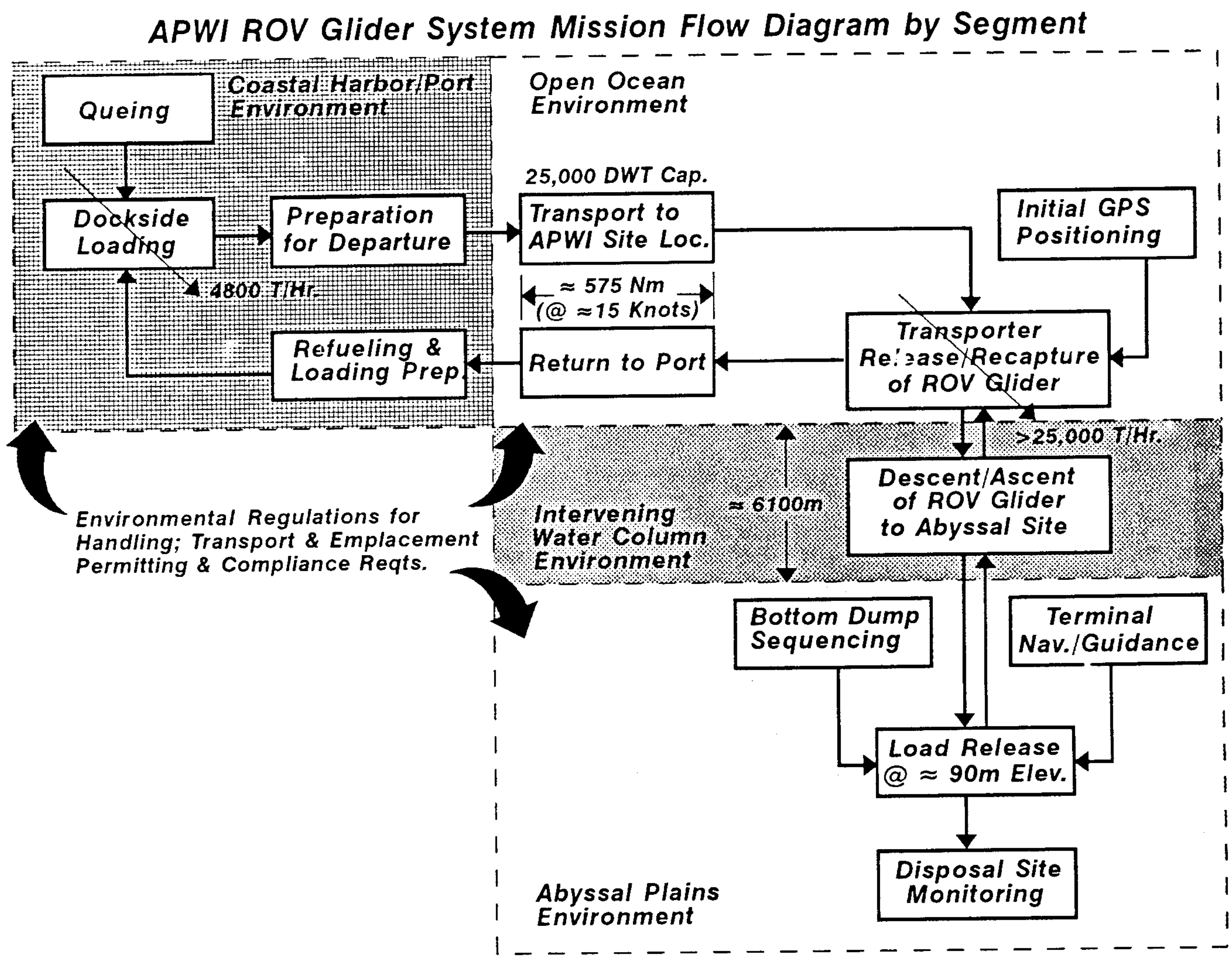


Figure 5.2.1-2
ROV Glider Process Flow Diagram

The ROV Glider is negatively buoyant when fully loaded. Assuming a cargo bulk specific gravity of approximately 1.25, the vehicle weight in seawater (fully submerged) will be 3870 Mg. Upon cargo release, the vehicle would have a positive buoyancy of approximately 520 Mg.

For transportation of the ROV Glider, an Integrated Tug/Barge (ITB) configuration would be the desired choice. The barge configuration (similar to a catamaran) uses twin hulls, each having a width of approximately 3.7 m (12 ft) and lengths of 222 m (728 ft), with an open space-frame deck structure span between the hulls. Major characteristics are as follows:

- Length OA of 230 m (755 ft); Length WL of 222 m (728 ft); Beam of 43.9 m (144 ft); Draft (Loaded) of 7.0 m (23 ft); Depth of 15.2 m (50 ft), and Displacement of 20,150 Mg.

The estimated displacement of 20,150 Mg at full load is as follows:

■ ROV Glider (at 7 m Draft)	11,530
■ Light Ship	8,620
Full Load Displacement	20,150

The estimated light ship weight is made up of the following:

■ Structural Weight	7,650
■ Machinery	70
■ Outfit	900
Light Ship Weight	8,620

The ROV Glider would be supported by the barge during loading, transiting, and launching operations using ARTUBAR linkages (similar to linkage employed to connect the tug to the barge). These linkages would be located along the interior walls of the twin hulls, and engage the port and starboard faces of the ROV Glider. The ROV Glider hexcell structure is capable of sustaining very large bending and shear loads, including any localized dynamic and/or wave impact loads. Comparison of the ROV Glider hexcell structure to finite element analyses performed for the Direct Descent Disk hexcell structure (Section 5.3) indicates that capability exists to sustain greater than 48.6 kPa (1000 psf) uniform loading at less than 84 MPa (12,000 psi) stress levels. In comparison, the hexcell structure for the ROV Glider has a section modulus of inertia 2.55 times larger, and an unsupported span of 1.22 times smaller (or 1.82 times the stiffness of the Direct Descent Disk). Assuming that the hexcell plate elements are structurally similar, the resultant ROV Glider hexcell structure would be 4.64 times stronger than the Direct Descent Disk.

The barge is capable of adjusting ballast to align the ARTUBAR linkages to the mating engagement features of the ROV Glider, either in port or at sea during recovery operations. Additionally, ballast adjustment is utilized to initialize launch conditions for the ROV Glider, whereby the glider is fully submerged prior to being placed into an approximate 40° pitch down attitude. This 40° pitch down attitude is achieved by release of all the ARTUBAR linkages except for the aft-most pair, allowing the ROV Glider to commence pitch rotation about the aft pivot point. On-board attitude sensors trigger release of the aft linkages such that the desired ROV Glider angle-of-attack is achieved.

The following discussion is based upon supporting analysis provided by Dr. R.A. Barr, Hydronautics Research, Inc., to identify performance characteristics of the ROV Glider.

A stable glide path is achieved by proper longitudinal and vertical separation of the center of gravity, C_G, and the center of buoyancy, C_B, and by providing the appropriate tail surfaces. Roll stability is satisfied by locating the C_G below the C_B. A suitable vertical separation of these centers would be 1 to 2 percent of the beam or about 0.3 to 0.6 m. Dynamic directional stability is assured, even during the initial stages of the glide, by providing neutral or positive static ("weathervane") stability in the vertical (pitch) and lateral (yaw) planes. To achieve this positive static stability, the Glider has a horizontal stabilizer foil at its aft end. This stabilizer has a 30 m span and an 8 m chord, and is supported by vertical stabilizers with chords and heights (spans) of about 5 m and 8 m, respectively. The 8 m span allows sufficient clearance of the horizontal foil from the Glider's hull, thereby minimizing possible adverse flow interference. The use of a streamlined afterbody allows the horizontal and vertical stabilizers to be of acceptable size.

The desired glide path is achieved by adjusting the horizontal stabilizer's angle of attack. A stable glide will occur when total body axis hydrodynamic forces equal the components of net weight (i.e., weight minus buoyancy). The relationships between glide slope, glide speed and net weight in water, and their dependence on the body drag coefficient and net weight ratio are determined from the summation of forces in the Glider's surge and heave axis. Results of these summations demonstrate the following relationships:

- Glide slope increases and descent time decreases with an increasing body drag coefficient, C_D
- Descent time decreases with increasing net weight
- Glide slope is independent of the net weight ratio

Finally, for operation at the minimum attainable glide slope considered desirable (i.e., less than 45°), glide speed (along the glide path) increases and descent time decreases with increasing net weight ratio.

Preliminary evaluations for various weight to buoyancy ratio (W/B), hydrodynamic drag coefficients, and varying glide slopes/angle-of-attack produce a vertical descent velocity of approximately 7 m/s. This would result in the ROV Glider requiring approximately 15 min to reach a waste emplacement site at 6100 m depth. The equivalent ascent velocity is estimated at approximately 1.3 m/sec, requiring approximately 78 min to return to the surface.

5.2.2 ROV GLIDER OPERATIONAL DESCRIPTION

The following sequence of events delineates the emplacement of waste at an APWI site using the ROV Glider:

- An ITB transporter arrives at the APWI site utilizing global positioning system (GPS) navigation and proceeds to an appropriate stand-off location for launching the ROV Glider. The stand-off distance is based on previous or real-time knowledge of currents throughout the water column as well as the planned glide path slope. While on its descent, the Glider, due to its ability to dynamically adjust its course, will be able to correct for current drift. For a weight to buoyancy ratio of 1.25, a C_D of 0.25, and a glide path angle of 40°, the speed along the path will be about 10.9 m/s. The vertical descent velocity is 7 m/s, resulting in a descent time to the cargo release depth of 6100 m of only 15 min. As the Glider nears the 200 m altitude above the seabed, where it releases its cargo, the horizontal (forward) speed is about 8.3 m/s.

  Primary Glider control will be on-board using pre-programmed flight plans with adaptive control; however, limited surface control can be accomplished using acoustic links. Conventional Ultra Short Baseline (USBL) sonar navigation equipment can track the departure from the surface ship and the arrival of an approaching beacon. Since the vehicle will be following a preset glide path, its depth profile will be known so the USBL navigation fixes can be verified or corrected for slant ranges by on-board processors. Since accurate navigation within close proximity of the dump site may not be possible due to shadowing and

reflections from waste containers, an extended approach path can be established outside the drop zone. The approach path can be marked with passive reflectors of the Glider's own sonar by using an active array of long baseline transponders. This extended run permits locking in a final acoustic position. Last minute course corrections for a specific drop site can then be made via inertial dead reckoning.

- As the cargo cells begin sequential release, the Glider begins pitching up and gaining buoyancy. On board electronics record the location of the drop as well as the individual status of each cargo cell.

- Following the release of the remaining cargo, the Glider eventually loses its forward momentum and begins to ascend due to its positive buoyancy. The rate of ascent is determined by the drag on the Glider which in turn is dependent on the Glider's attitude during the ascent. If, in its lightship state, it is evenly trimmed, then the drag will be greatest and the ascent rate will be about 1.3 m/s. Therefore the Glider will surface in about 78 min. By altering the trim to a bow or stern up attitude, drag will be reduced and ascent rate increased. The optimum ascent rate can be determined in a later study. The ascent of the Glider will trigger the release of the pendant buoy system housed in the stern fairing of the Glider. Although the Glider's ascent will be tracked on the ITB's sonar to avoid collision, the buoy will serve as a mechanical adjunct to visually warn of the Glider's impending surfacing. The pendant buoy would also contain a transponder for the ITB to observe its ascent offering further tracking redundancy. A minimum safety zone (and, by calculation, the approximate time for the Glider's re-surface) can be established based on the length of the buoy's tether. For example, a 1500 m tether would dictate to surface vessels a minimum safe standoff distance of 1500 m from the pendant buoy. Sighting of the buoy would indicate Glider re-surfacing in about 19 min. The Buoy will always precede the Glider because of its lower drag.

- Once the Glider has surfaced, the pendent buoy can be retrieved and used as a tag line to winch the Glider back onto the carrier. If docking is not feasible due to high sea state, the Glider can remain under tow until safer conditions prevail.

The operational timeline for the ROV Glider is shown in Figure 5.2.2-1.

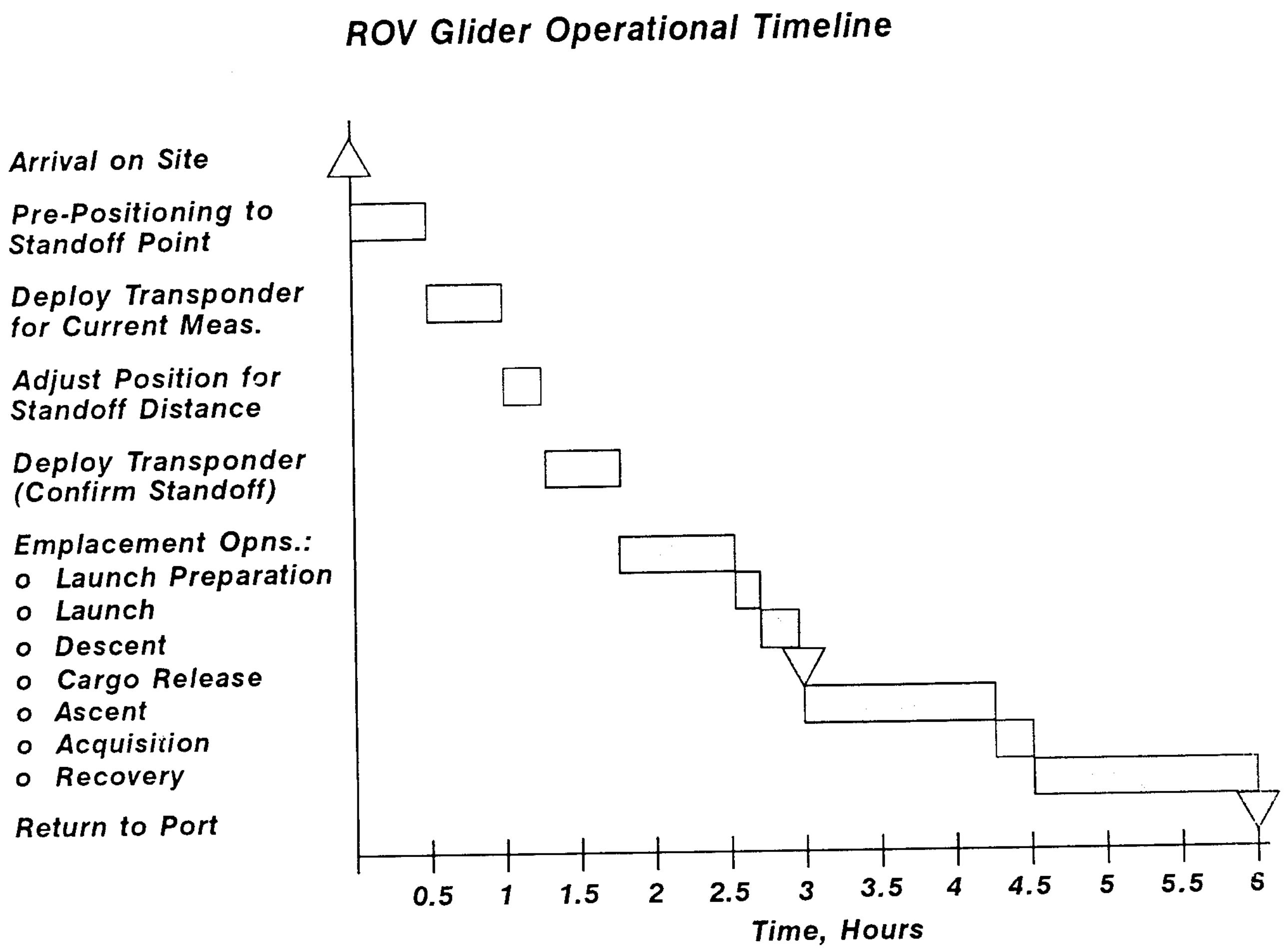


Figure 5.2.2-1
ROV Glider Operational Timeline

5.2.3 ROV GLIDER SUMMARY OF ADVANTAGES AND DISADVANTAGES

Using current state-of-the-art undersea technology and extrapolating from deep ocean operational experience, abyssal plain waste isolation can be safely, accurately and repeatedly performed using an unpropelled (yet actively controlled) subsea Glider delivery vehicle. The concept is fundamentally sound from an engineering and operational perspective. The advantages to the ROV Glider concept are:

- Component parts are modular, requiring low technology construction techniques;
- The Glider's design and operational requirements are readily suited by the proven integrated tug-barge (ITB) transport system;
- The Glider's hydrodynamic design requires only small amounts of active control during descent;
- The Glider ensures repeatable, accurate emplacement and can self correct for current drift during descent by altering its glide path;
- The emplacement pattern is closely clustered allowing simplified site monitoring and, if needed, future remediation; and
- Essentially autonomous operation permits limited human intervention while the Glider is undersea.

There are some disadvantages to the Glider and these must be considered as well:

- Launch and recovery of an extremely large vessel at-sea always presents operational risk;
- The Glider must be equipped with suitable marker lights, sound signals, and electronic aids to prevent it from becoming a hazard to navigation if unattended while at sea; and
- Near-total cargo release must occur for Glider to resurface.

5.2.4 ROV GLIDER KEY TECHNICAL ISSUES

- **Glider Stability:**

  Unique to the Glider is its change of buoyancy from negative to positive upon releasing its cargo while in forward motion. While the concept is viable, more research and empirical testing will be required to ascertain the vehicle and cargo dynamics at, during, and following release.

- **Acoustic Navigation:**

  In concept, the ROV Glider is to autonomously navigate to the exact drop location relying on acoustic telemetry to verify and/or correct its flight path. Noise, data speed and data integrity are known problems working with underwater acoustical telemetry. Noise is traditionally generated by a vessel's propulsion system, but in this case the noise would result from flow over the Glider surfaces as it moves at approximately 11 m/s. Acoustical data transmission speed and integrity are problems that autonomous underwater vehicles (AUVs) have been dealing with for several years. The development of the Glider

concept would require some additional experimentation to verify that the use of acoustical navigation meets its reliability needs.

Other technical issues related to the ROV Glider are similar to the Surface Emplacement concept. These are:

- **Bag Survivability:**

  It is anticipated that the bags will reach terminal velocity in a less than 15 m (50 ft) of free fall, based on the COE experiments. This indicates that the bag survivability issue is the same for the ROV Glider (and Direct Descent Disc) concepts, with 100 to 200 m of free-fall, as for the Surface Emplacement concept with over 6000 m of free-fall. The issue of bag survivability upon landing on the seafloor is important for all three concepts utilizing bags.

- **Cargo Bay/Trap Door Design:**

  As with the Surface Emplacement concept, trap door and cargo bay design of the ROV Glider is important to prevent bag tearing during release from the cargo cells.

- **Throw-Away Transponders:**

  Battery powered/multiple channel transponders will be required to assure that the bags are emplaced within the desired isolation site monitoring area.

- **Geotextile Bags:**

  The bags used in the ROV Glider concept to contain the three waste streams are smaller in size, and therefore use more fabric, than those used for Surface Emplacement. The issue of selecting the appropriate type of bag material and verification that production rates can be met is critical.

5.2.5 ROV GLIDER MANUFACTURABILITY/PRODUCIBILITY ASSESSMENT

The components of the ROV Glider emplacement concept, the ITB transporter, and the ROV Glider itself all benefit from either established construction techniques and standards or new, but straightforward and simple techniques.

The naval architecture of designing a suitable integrated-tug-barge transport system for the ROV Glider has existed for some years and no technical or costly financial obstacles are anticipated in this area. Furthermore, although the ITB tugs must be constructed specifically for ITB operations, their size and form are still largely conventional and can be constructed by any number of smaller domestic shipyards allowing competitive bidding and therefore economic savings.

The ROV Glider is largely of modular construction with its hexagonal cargo cell forming the fundamental building block. However, the cell itself is formed from panel sections which can be easily fabricated from straight elements by established aluminum welding techniques in fabrication job shops throughout the nation. The panels' finished size allows for transport via common carrier to any convenient shipyard for final assembly. Shipyard assemblies are also streamlined and low cost since no field welds are required; the modular concepts are bolted together.

Insertion of syntactic foam into the tubular members is a new technique in ship building. However, foam insertion has been used and proven in other industries, so this should not present an obstacle to vessel construction.

5.3 DIRECT DESCENT DISK

5.3.1 DIRECT DESCENT DISK CONCEPT DESCRIPTION

The Direct Descent Disk concept is illustrated in Figure 5.3.1-1, with an overall concept process flow diagram as illustrated in Figure 5.3.1-2. Figures 5.3.1-3 through 5.3.1-5 illustrate unique features of the Disk including the Disk integrated with its respective Floater Module, and the resultant ITB configuration with 25,000 DWT cargo capacity.

Figure 5.3.1-3 depicts the Direct Descent Disk by itself and illustrates an interior "beehive" cargo matrix contained within an exterior set of vortex shedding control surfaces. For each Disk, 169 individual hexcell cargo bays of 19 m^3 (25 yd^3) capacity, or 22 m^3 (28.7 yd^3) capacity, are arranged in a large hex array of principal dimensions 32.3 m (106 ft) X 7.3 m (24 ft) depth. The overall diameter of the Disk is 36.6 m (120 ft). The cargo matrix cell structure consists of sandwich panel composites of 9.5 mm (0.375 in) thick 6061-T6 aluminum face plates bonded to a 127 mm (5.0 in) thick sandwich core of Hysin 55 syntactic foam. Joining of the hexcell panels to one another is accomplished by the use of extruded form aluminum tieplates, 0.2 m (0.67 ft) wide by 7.3 m (24 ft) long, formed into a 'V' of 60° included angle, three each per vertex assembly, and riveted to one another through the respective sandwich panel(s). The vortex shedding control surfaces are similarly constructed. The resultant configuration provides an exceptionally high-strength, very low-weight structure which is positively buoyant in seawater. Additional features illustrated in Figure 5.3.1-3 include the following:

- Louvered Drag Brakes--facilitate rapid deceleration of the Disk at approximately 100 m above the abyssal seafloor isolation site, simultaneously with ganged release of the bagged waste from all of the cells. The braking panels are mounted on centerline shafts, gang-actuated by segment with a single hydraulic ram for each of the six segments. Centerline mounting is utilized to achieve cancellation of hydrostatically induced loads during the braking operation, thereby minimizing the forces required to achieve actuation. Ram size is estimated at 100 mm (4 in) bore, 63 mm (2.5 in) diameter rod, and 0.3 m (1 ft) stroke, yielding a total stored energy requirement of approximately 17 liters (l) (4 gal) of hydraulic fluid at less than 6.9 MPa (1000 psid) above ambient sea pressure.

- Indexable Rotary Latching--permits release of the cell lower trap doors. Topside mounted hydraulic rotary actuators drive shafts located within each vertex, and connect to a three-prong bearing plate. The plate prongs, or tabs, provide bearing support for the cell trap door assemblies. Actuator sizing for overcoming the imposed bearing load from the trap doors, assuming a three-point support, yield a required actuator delivery torque of 607 m-N (5376 in-lbs) at an effective bearing pad/trap door static friction of 0.1 and maximum moment arm of less than 152 mm (6 in). A rotary actuator similar to the Rotac Model XL-34-2V, double vane, 100° rotation capability, could provide 6750 in-lbs at 6.9 MPa (1000 psid), and have a 1.3 X 10^5 mm^3 (7.8 in^3) displacement for 60° of rotation. Simultaneous actuation of all 169 actuators would require approximately 25.5 l (6 gal) of hydraulic fluid at less than 6.9 MPa (1000 psid) above ambient sea pressure. Actuator size for this model is approximately .0027 m^2 (4.25 in^2) by 0.079 m (3.1 in) deep with a mass of 12.2 kg (27 lbs).

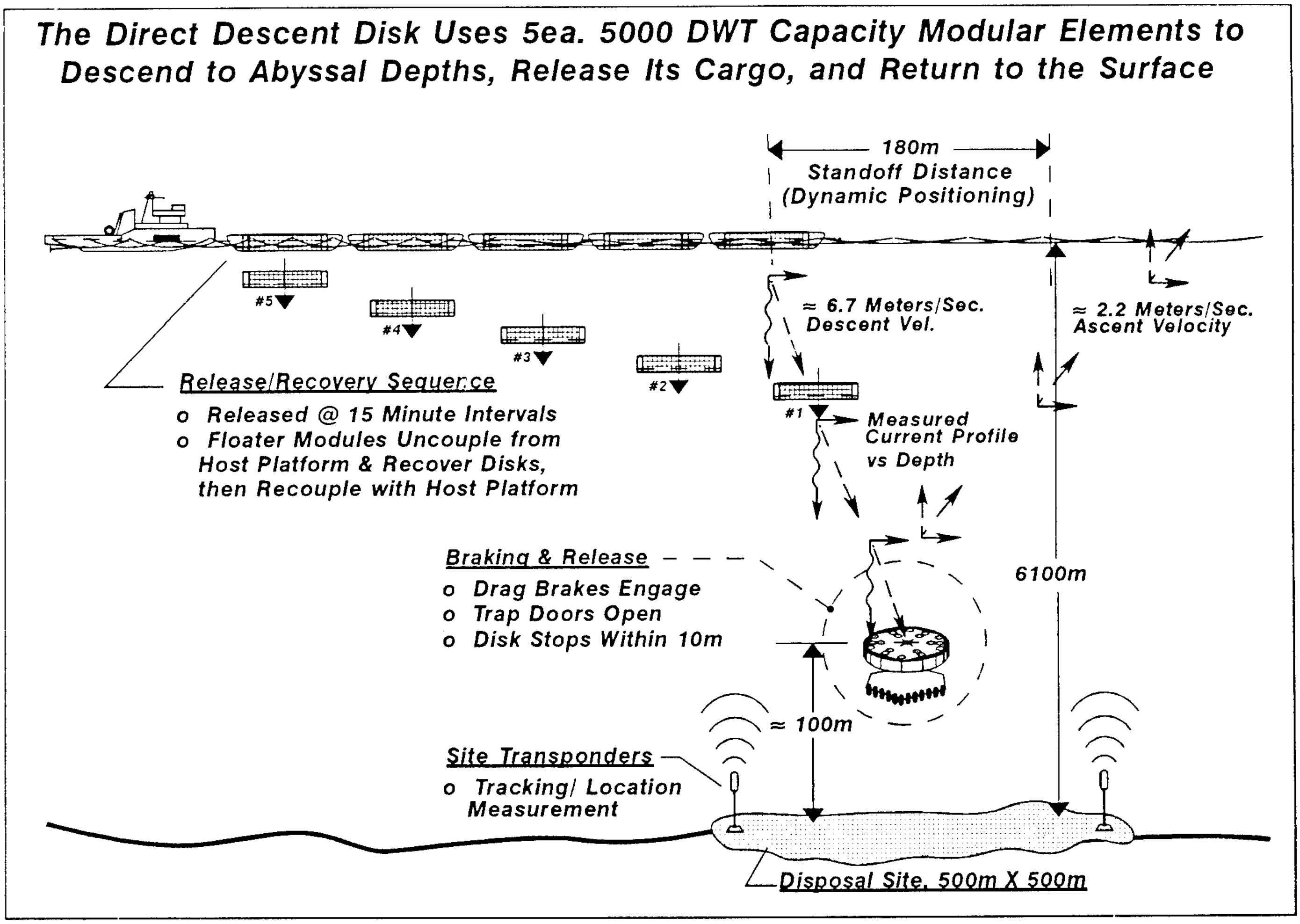


Figure 5.3.1-1
Direct Descent Disk

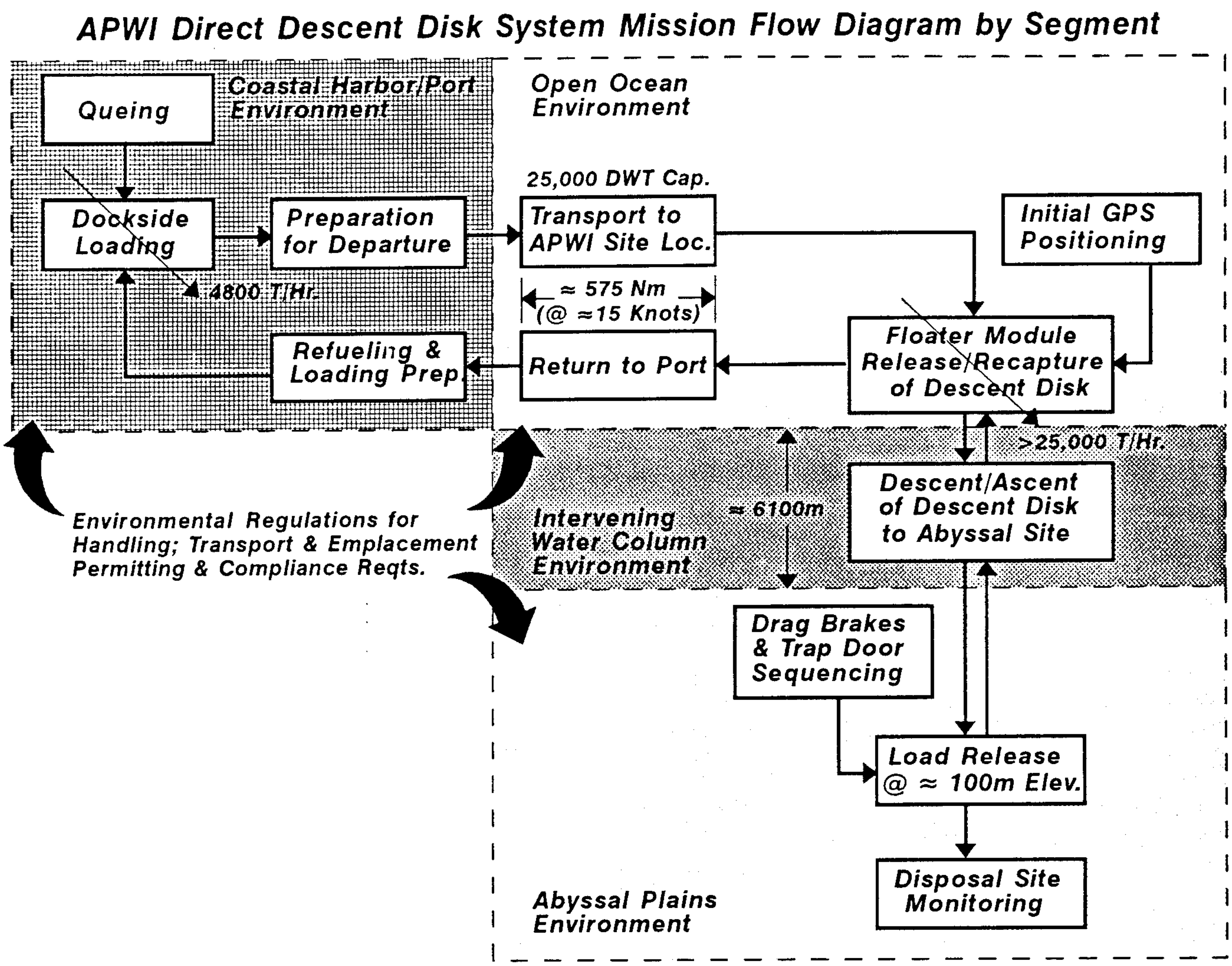


Figure 5.3.1-2
Direct Descent Disk Process Flow

Direct Descent Disc, 4820 Yd³ Capacity, with 169 Cargo Bay Cell Elements in a Hexcell "Beehive" Matrix, Displacement in Seawater @ +107T (Min.)

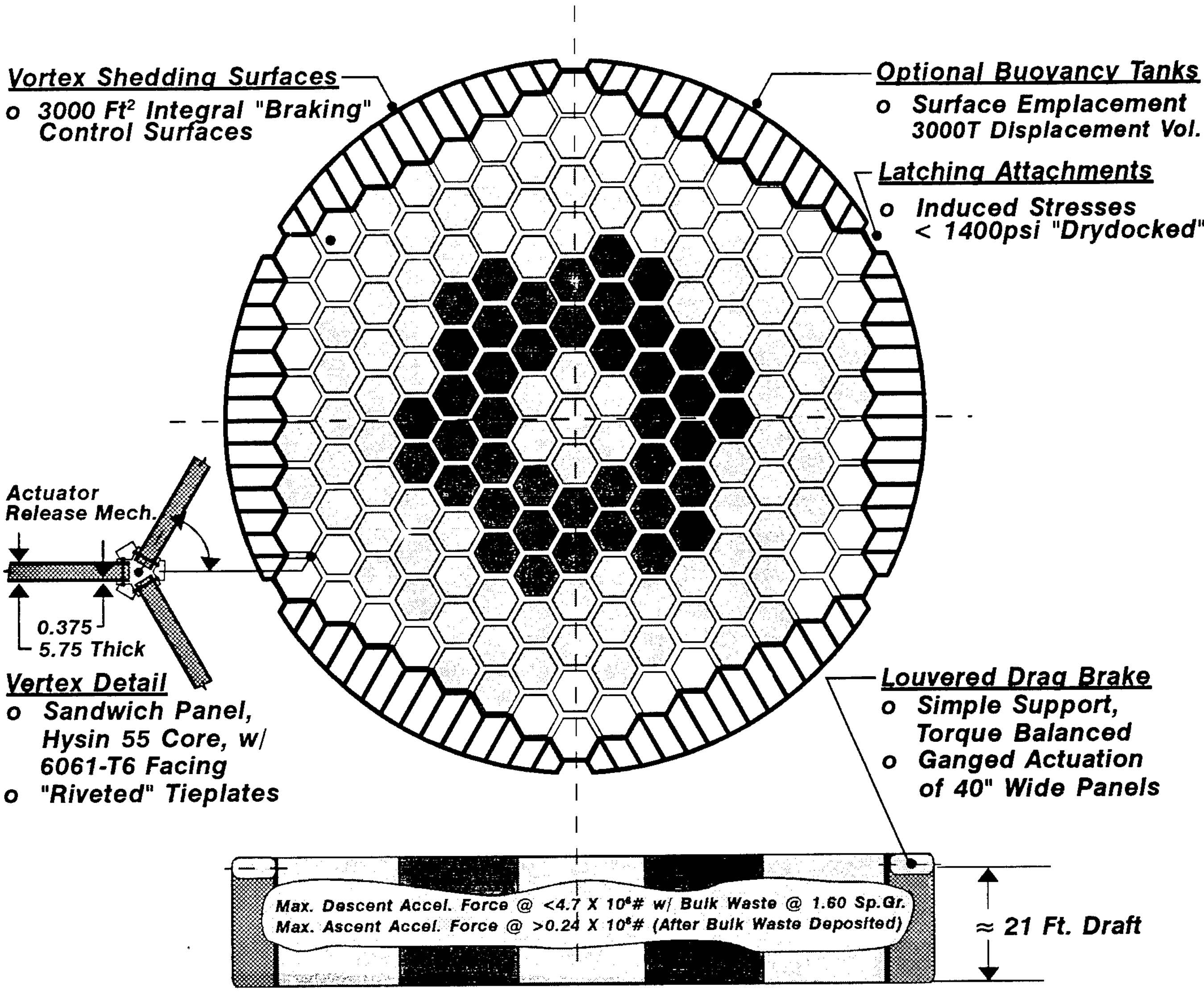


Figure 5.3.1-3
Direct Descent Disk with "Beehive" Cargo Matrix

4300T Displacement Floater Module Configuration for Segmented ITB, Self-Propelled, Disk Recovery Via Driving Over the Surfaced Disk (Ref. Detail A for Integrated Tug/Barge Transport Configuration)

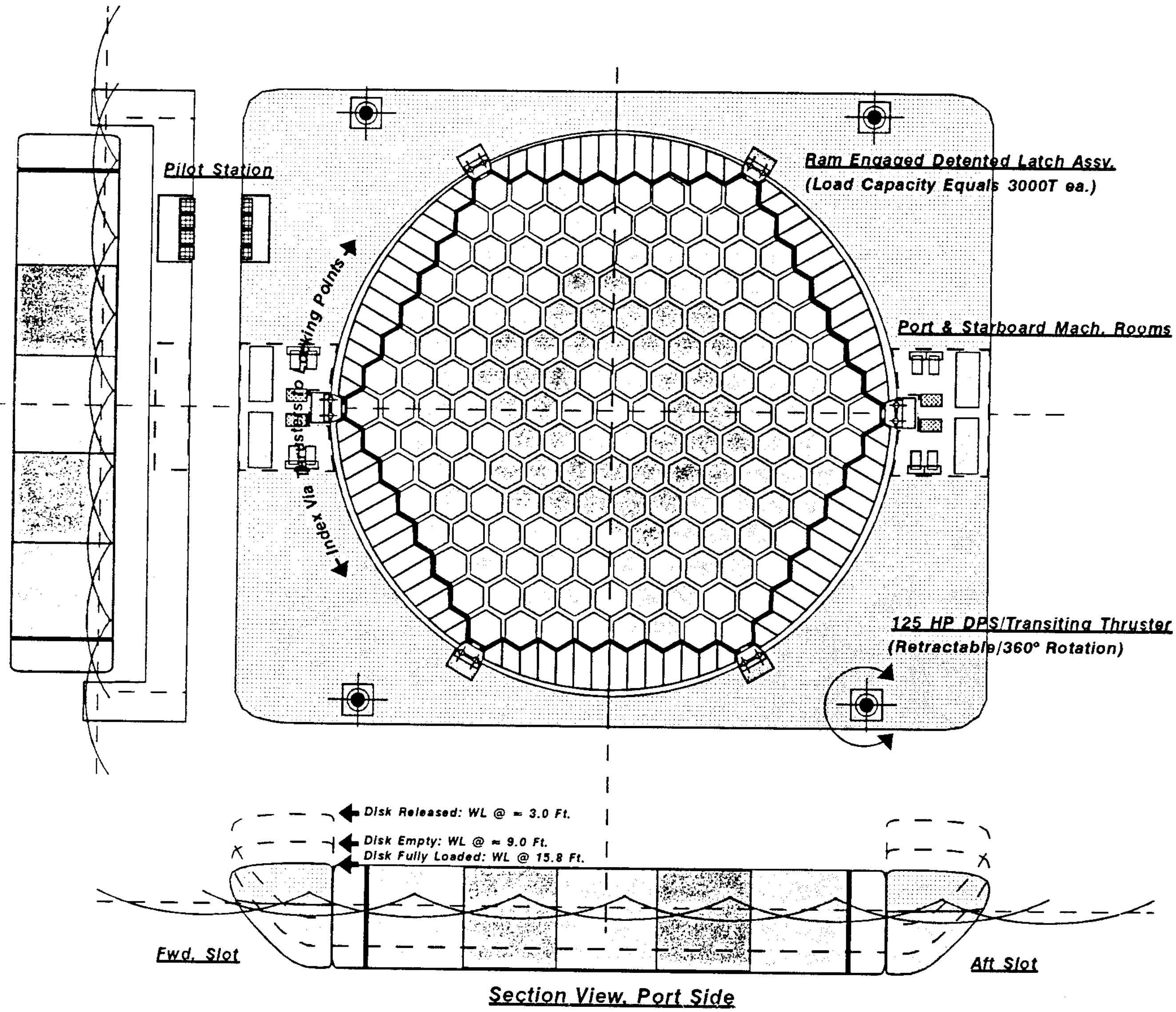


Figure 5.3.1-4
Direct Descent Disk Integrated with Floater Module

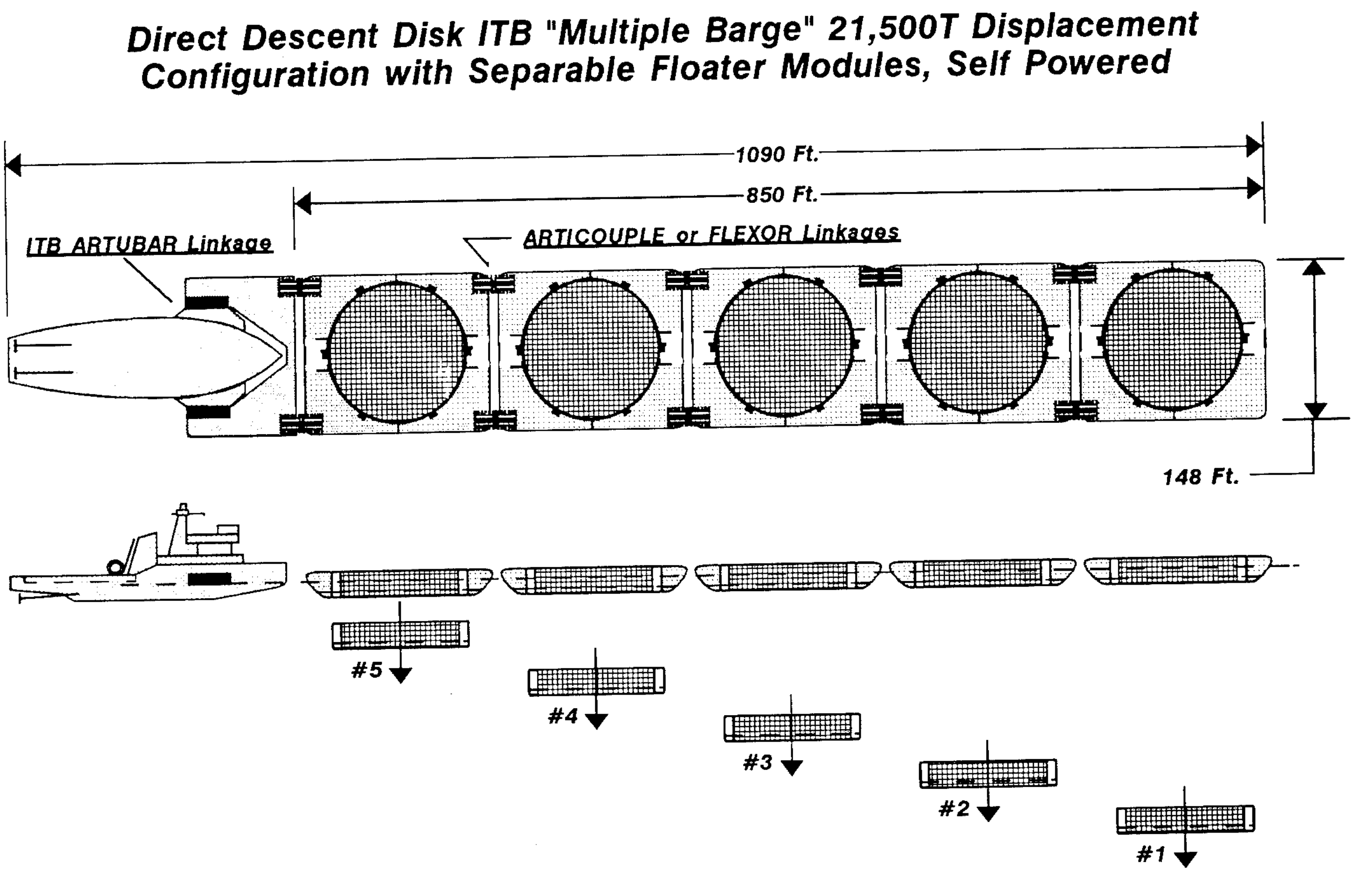


Figure 5.3.1-5
Direct Descent Disk ITB Configuration

- Cell Trap Doors--configured to be neutrally buoyant, are pivoted from one of the cell facing walls with load bearing sleeve bushings similar to Rulon. Dual rotary hydraulic actuators, located at each end of the trap door pivot shaft, provide means to effect closure of the trap door after release of the bagged waste. Rotac Model XL-32-2Vs would suffice for this function, providing a net torque of 763 m-N (6,750 in-lbs). Simultaneous actuation of all 169 trap door assemblies would require approximately 25 l (6 gal) of hydraulic fluid at less than 6.9 MPa (1000 psid) above ambient sea pressure. The actuator for this model is approximately 0.0027 m^2 (4.25 in^2) by 0.053 m (2.1 in) deep and has a mass of 9 kg (20 lb). The closure sequence would commence 4 to 6 seconds after load release, in order to assure clearance of the bagged waste (including that of the virtual mass of water passing through the now empty cargo matrix). Within this same time period, the Disk would decelerate to a descent velocity of approximately zero meters per second, thus permitting closure of the trap doors to occur under essentially zero hydrodynamic loading, and consequently minimizing the required actuation torque loads. Similarly, the rate of closure of the trap doors is kept to a period of 2 to 4 seconds in order to minimize induced reaction torque loads. Figure 5.3.1-6 illustrates predicted performance of the Disk during the final braking operation, with release of the cargo. The analysis presented in figure 5.3.1-6 illustrates "worst case" braking conditions with a cargo bulk specific gravity of 1.60. Actual cargo bulk specific gravity will be approximately 1.25 (Section 5.6.5.3), thus braking capability is robust.

- Vortex Shedding Surfaces--provide improved stability to a heavy object in free fall descent, reducing both rotational instability and pitching instability. They are dematable, such that resultant beehive cargo matrix has a principal dimension of 32.3 m (106 ft), permitting passage through the Panama Canal. The dematable surfaces would be stacked on top on the matrix for this passage. A Surface Emplacement configuration is also feasible, by replacement of the vortex shedding surfaces with ballast tanks, converting the Direct Descent Disk to a "Floater Module". This "Floater Module" could be an integral part of a transport vessel similar to that discussed in Section 5.1.

- Latching Attachments--six-point, equally spaced about the cargo matrix, at a load rating of 27 meganewtons (MN) (6×10^6 pounds force (lbf)) per attachment point. Figures 5.3.1-7 and 5.3.1-8 illustrate two loading conditions evaluated by finite element methods (Algor), which indicate exceptionally high strength capability for the assembled configuration. This evaluation indicates the potential to achieve a 6-point support feature for the fully loaded Disk, capable of sustaining 5-Gs of loading, at a design factor-of-safety of 2.5.

The estimated displacement of 6963 metric tons (Mg) for a Floater Module at full load is summarized as follows:

■ Cargo Deadweight	5,837
■ Light Ship	1,126
Full Load Displacement	6,963

The Light Ship weight consists of the following breakdown:

■ Plate Aluminum Weight	350.8
■ Vertex Aluminum Weight	117.4
■ Attachment Hardware	25
■ Syntactic Foam	501.8
■ Trap Doors/Act. Sys.	131
Light Ship Weight	1,126

The estimated negative displacement of the Direct Descent Disk is 2085 metric tons (Mg) in seawater, fully loaded, and reflects the operational condition of being a free flooding, pressure-tolerant vessel for descending to abyssal depths. The net positive buoyancy of the Disk is approximately 107 Mg, after release of the cargo, providing the means for the Disk to buoyantly return to the surface. Descent terminal velocity is approximately

6.7 m/s (21.9 ft/s), and ascent terminal velocity is approximately 1.6 m/s (5.3 ft/s), based upon a coefficient of drag of 1.17, and a Disk projected area of 772 m^2 (8300 ft^2). Note that if the trap doors remain open during ascent, the ascent terminal velocity would be approximately 2.2 m/s (7.2 ft/s). Upon activation of the louvered drag brakes, with simultaneous release of the bulk cargo, the Disk deceleration would occur over an approximate 3.5 second period, stopping its descent within a distance of approximately 7.3 m (24 ft). The braking sequence is illustrated in Figure 5.3.1-6.

Color Insets:

Figure 5.3.1-7 - Displacement Magnitude at Uniform Load Distribution at Approximately 21 kPa (3 psi)

Figure 5.3.1-8 - Stress Distribution Magnitude at Uniform Load Distribution at 21 kPa (3 psi)

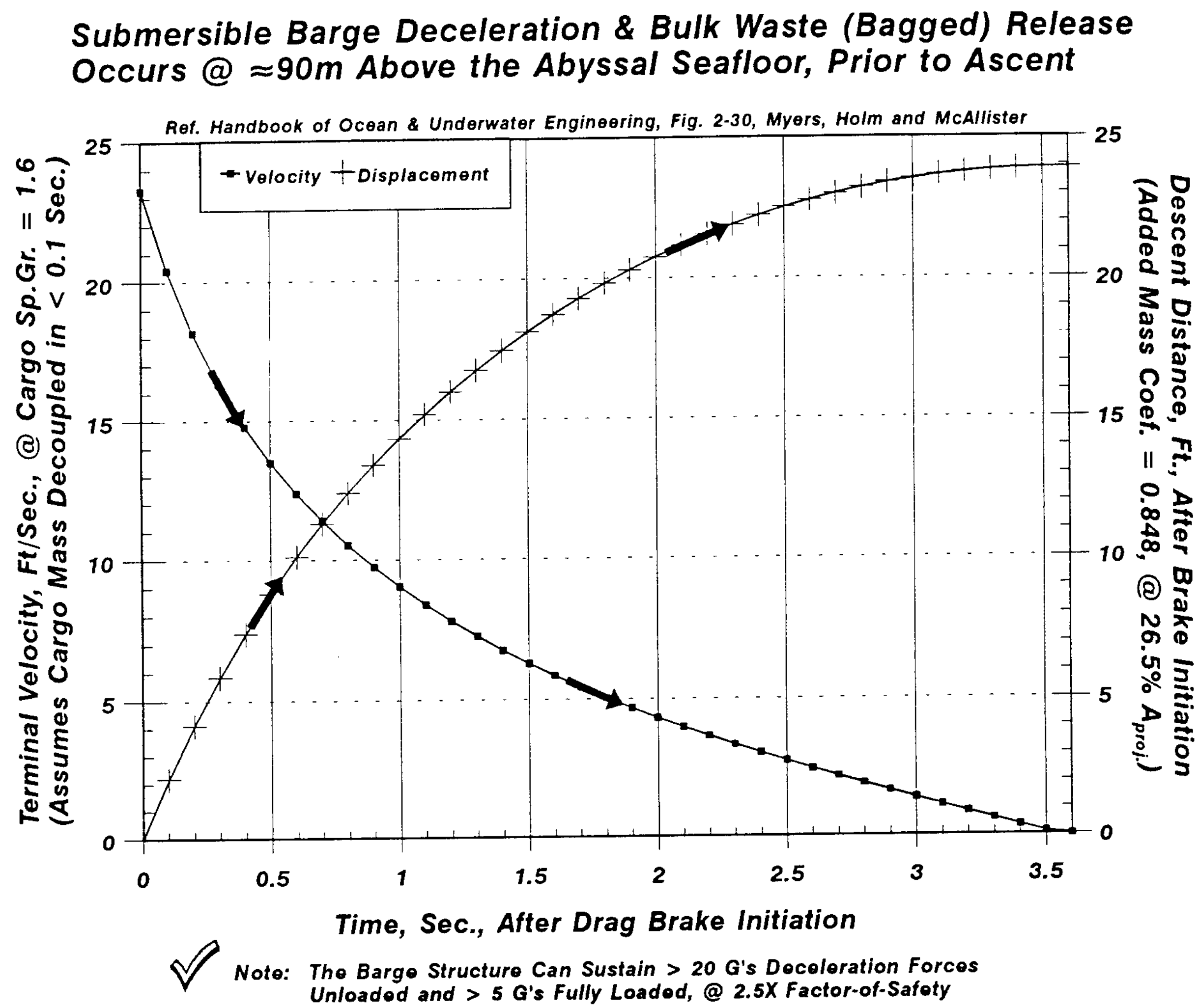
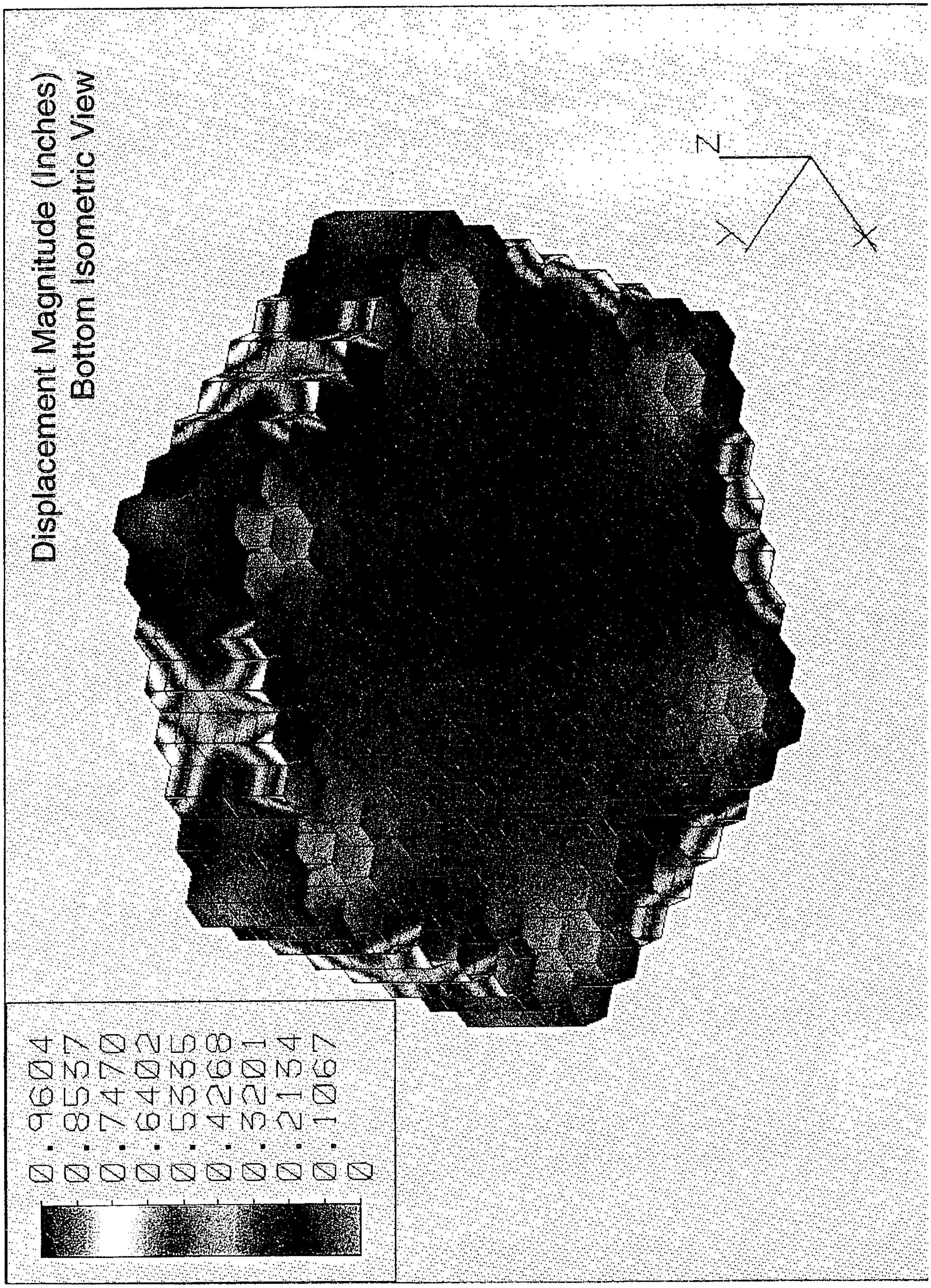
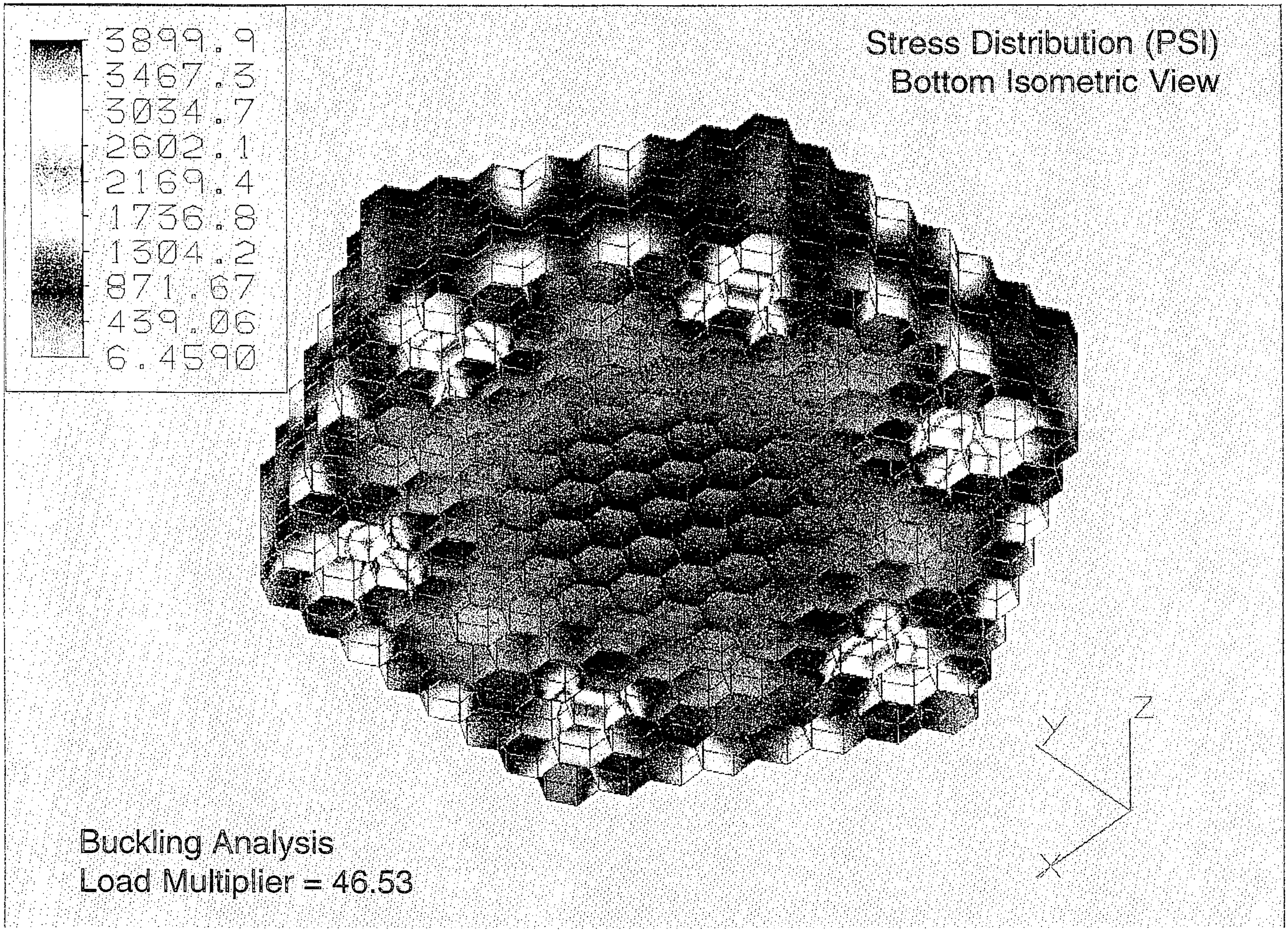


Figure 5.3.1-6
Predicted Performance of Disk During Braking



Displacement Magnitude (Inches)
Bottom Isometric View
0.9604
0.8537
0.7470
0.6402
0.5335
0.4268
0.3201
0.2134
0.1067
0
Z



3899.9
3467.3
3034.7
2602.1
2169.4
1736.8
1304.2
871.67
439.06
6.4590
Stress Distribution (PSI)
Bottom Isometric View
Y
Z
X
Buckling Analysis
Load Multiplier = 46.53

Figure 5.3.1-4 illustrates the proposed Floater Module configuration for implementation of the Direct Descent Disk method. The Floater Module provides an additional 4300 metric tons (Mg) of displacement, or positive buoyancy, to that of the Direct Descent Disk. It is attached to the Disk at six points by ram-engaged detented latching assemblies of 27 meganewtons (MN) (6 X 10^6 lbf) load capacity each. The integrated Floater Module/Direct Descent Disk configuration would have a fully loaded draft of approximately 4.9 m (16 ft), a beam of 41.5 m (136 ft) and a length of approximately 51.2 m (168 ft). Slots, located on the hull bottom, 4.9 m (18 ft) high by 37.8 m (124 ft), wide are provided on the port and starboard sides of the module to permit recovery of the Disk after the emplacement operation. The slot dimension height is based upon the need to provide clearance of approximately 1.5 m (5 ft) between that of the Floater Module underside and that of the surfaced Disk. The Floater Module is self-powered, uses four deployable thrusters, and provides the means to recover the Disk in the open ocean in sea state five conditions by "driving over" the Disk, positioning itself to align the latching assemblies to that of the Disk attachment points, engaging and hoisting the Disk to a fully retracted position within the module, and subsequently returning to the host vessel for return to port.

The Floater Module may be considered to be a mini-ITB, capable of independent operations in coastal ports and in the open ocean. The design range for independent operations would be approximately 90 km (50 nmi), with transiting speed of approximately 2.6 m/s (5 knots). Once loaded in port, integration into the transport configuration would take place. This integration would consist of linking five Floater Modules together with an ocean going tug. Once linked together, the Floater Module reverts to an unpowered barge segment of the fully integrated ITB configuration. At the APWI emplacement site location, the barge segments sequentially release their Direct Descent Disk at approximately 15 minute intervals. Based upon average current conditions of 0.21 m/s (0.4 knots) existing in the water column, and having a total time of descent and ascent of approximately 67 minutes, the Disks would resurface approximately 3100 m down-current of the point of release. The Floater Modules track their respective Direct Descent Disks during descent and ascent. Once the Disks resurface, each Floater Module uncouples itself from the host ITB and initiates recovery operations. Recovery operations are estimated to require from a minimum of one to a maximum of four hours.

Figure 5.3.1-5 depicts the fully assembled ITB configuration. This configuration employs positive engagement articulated latching systems, similar to SEALINK or FLEXOR, for connection of the individual Floater Modules. For simplicity of operations, the aftmost Floater Module may remain connected to the tug while the other four modules will proceed independently to recover the surfaced Disks. In a seaway, it is anticipated that the Disks will experience relatively small motions and velocities in all modes. Because of the Disk's low freeboard and small waterplane area, waves will tend to wash over the Disk. Consequently, while the righting moments are large, virtual inertias in angular and horizontal plane motions are also large. Because of the Disk's circular platform, yaw of the Disk is not an issue for remating. The Disk's heave excitation is small, while the deployed brakes will add substantially to the damping. The Floater Module, riding unloaded and light, will be heavily damped in all modes, but it is anticipated that its responses in a seaway will be greater than the Disk's and are expected to be the limiting factor for Disk recovery.

The Floater Module's freeboard and consequently the initial vertical clearance between the module's underdeck structure and the top of the Disk will be selected to reduce the probability of contact between the module's underdeck structure and the top of the Disk, between the two bodies prior to indexing and engagement of the locking devices, to an acceptable level. Prediction of the rms relative motions between the module and Disk will require further analysis and scale model testing as part of further development. It is anticipated that the module would approach the Disk from the leeward side, thus taking advantage of the Disk's ability to provide wave attenuation by breaking of overtopping waves. The interior surfaces of the Floater Modules will be provided with suitable fendering or batterboards, with the locking devices protected in recessed portions of the fendering until ready for engagement.

The recovery of the Disks in a seaway, and the relinking of the Floater/Disk units together for the return transit, will be subjected to further analysis as the concept is developed.

An alternative semi-catamaran barge or well ship configuration, similar to that of the ROV Glider, may also be considered. The well-ship would provide an open bottom for dropping the full disks and a gate at the stern for recovery of the empty Disks.

The floater modules would be used solely for coastal operations and, at the APWI site, used as hoistable "spacer modules" in the well, to help locate the disks and to give continuous bottom surface for transit. These "spacer modules" would be hoisted up out of the way inside the well to allow the Disks to float past into position during recovery, one at a time. This alternative approach eliminates having four extra manned and powered craft at the disposal site. The tug would be used to maneuver the Disks up to the stern gate of the barge, then pass a line to winch them into final position.

Potential advantages to this alternative approach are as follows:

- A large semi-catamaran barge or well-ship will ride better than the individual floater modules in most seas, and if the barge is kept head to sea by thrusters, will also provide a sheltering effect for the Disk as it approaches the stern gate.

- This approach replaces a difficult seakeeping relative motion problem for capture and/or reconnection of the modules, with a purely mechanical systems problem inside the carrier.

5.3.2 DIRECT DESCENT DISK OPERATIONAL DESCRIPTION

Release of the Direct Descent Disks at the isolation site location would occur with the following scenario of operation:

- The ITB transporter configuration, consisting of five Floater Modules, arrives on-site, identified by on-board navigation/global positioning system, and dynamically positions to a predefined standoff distance for release of the Direct Descent Disks. This standoff distance is based upon previously established knowledge of current conditions existing throughout the water column, such that adjustment is made for drift due to the current flow field over the Disk's free-fall descent. The free-fall descent velocity will be approximately 6.7 m/s, and, for an abyssal seafloor isolation site located at 6100 m depth, with average currents in the water column of 2.1 m/s (0.4 knots), the required standoff distance would be approximately 180 m.

- The ITB transporter interrogates previously deployed and located bottom mounted transponders to confirm its relative position with respect to the site, and the status of the bottom transponders in the site range. A deployable transponder is released, having a terminal velocity of 6.7 m/s. The transporter confirms that it has landed within the target area. If not, adjustment is made to the vessel's relative position, and a second transponder is released. The required time for the first (and any subsequent trial) is less than 16 minutes, before commencement of the next step.

- The ITB transporter initiates the sequential release of the five Direct Descent Disks at approximately 15 minute intervals, proceeding at approximately 3 knots speed of advance, on a track perpendicular to the prevailing current. The Disks are released at 500-1000 m intervals in a line running perpendicular to the current to minimize potential for collision between Disks in their travel to and from the seafloor.

The descent and ascent after release of cargo of the individual Disks is tracked by the host platform using transponders operating on a unique frequency, and monitored using equipment similar to the Benthos DS-7000-16 Acoustic Signal Processing Deckset. The transponders would operate in a useable frequency range of 7 to 15 kHz, on 1 Hz increments, and would be matched to a high performance hull mounted transducer for deep water applications. The Deckset interrogates each Direct Descent Disk as it nears the seafloor and tracks it to its point of cargo release, approximately 100 m above the seafloor. This position is logged by vessel personnel and maintained in permanent record-keeping form to comply with anticipated permitting requirements.

- The Direct Descent Disk initiates simultaneous activation of the drag brakes and release of the cargo cell trap doors at approximately 100 m above the seafloor. The bagged waste continues towards the seafloor at a velocity of approximately 5.3 m/s as the Disk decelerates to zero velocity within a distance of approximately 10 m. The Disk then proceeds to ascend at a terminal velocity of approximately 2.2 m/s.

- Recovery operations commence once all disks have returned to the surface, with each of the Floater Modules performing the following sequence of operations:

  - Disengagement from the host platform, acquisition and tracking of the respective disk to the recovery location
  - Transiting at 3 to 5 knots to the disk location, and final positioning maneuvers for disk engagement
  - "Drive-over" capture of the disk, and alignment with latching assemblies by ballast adjustment
  - Latching engagement and de-ballasting, preparation for return to the host platform location
  - Sequential reengagement of the individual Floater Modules into the ITB configuration, and return to port

The operational timeline for the Direct Descent Disk concept is shown in Figure 5.3.2-1.

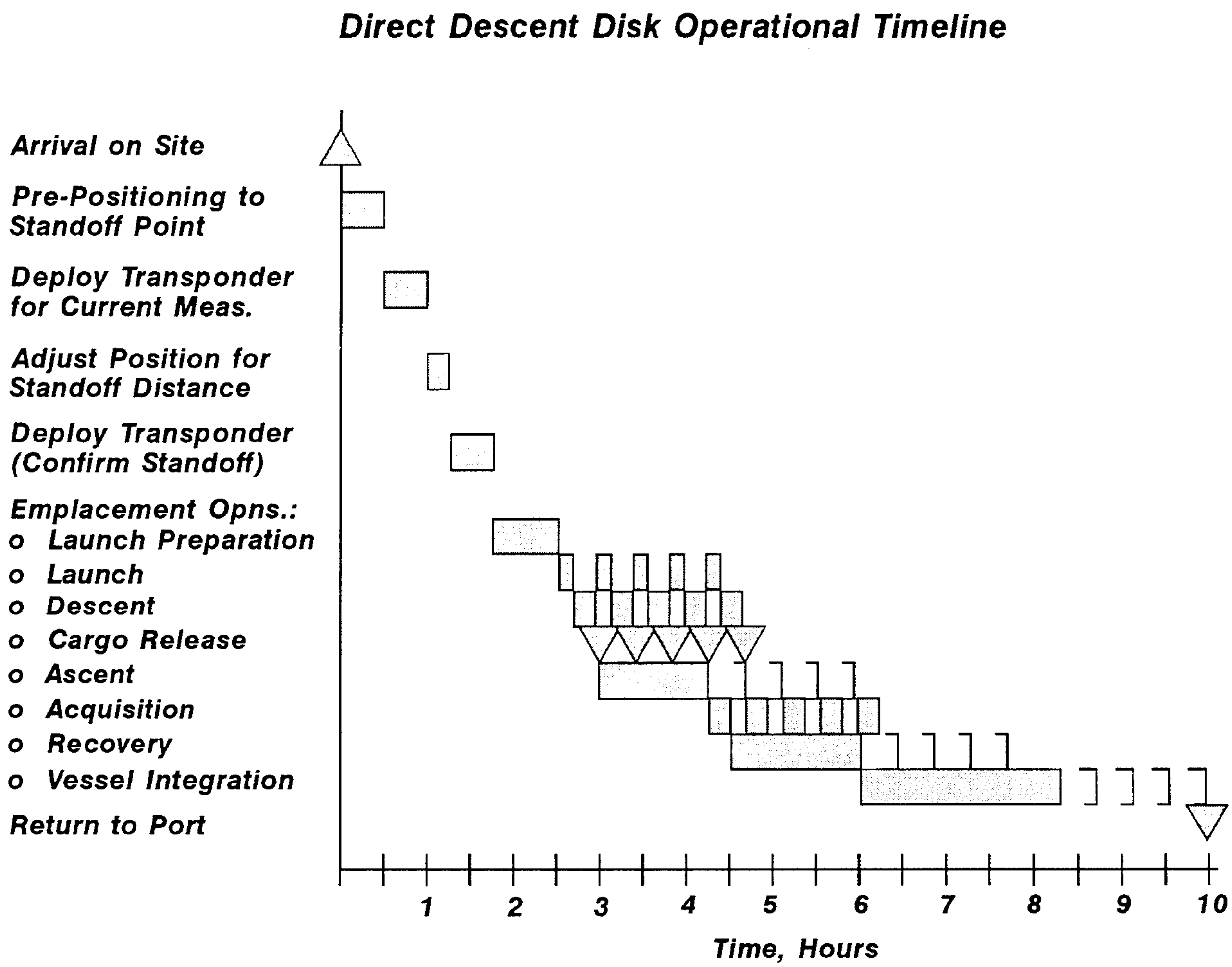


Figure 5.3.2-1
Direct Descent Disk Operational Timeline

5.3.3 DIRECT DESCENT DISK SUMMARY OF ADVANTAGES AND DISADVANTAGES

The Direct Descent Disk provides the capability for achieving submersed emplacement of large tonnages of bulk waste into designated APWI sites, mimicking previously demonstrated operations by the U.S. Army Corps of Engineers in water depths of approximately 100 m with bagged dredged material. The isolation pattern of the emplaced waste would be clustered in approximately 40 m diameter watch circles, versus that of the Surface Emplacement approach described in Section 5.1, which would be at least five times larger. Additionally, the Disk is an inherently stable design, and requires no active control during descent through the water column, and would therefore yield repeatable, accurate emplacement.

The use of an ITB vessel configuration consisting of barge segments, or Floater Modules, results in an equivalent Light Ship displacement of less than 7740 metric tons (Mg), as compared to the Surface Emplacement transporter Light Ship displacement of 11,600 Mg. This yields significant savings in shipyard fabrication costs.

The disadvantages are:

- Requires open ocean recovery of five Floater Modules, decoupling and recoupling into the ITB host vessel configuration.
- Requires that greater than 98% of the bagged bulk waste be released, otherwise the Disk possesses insufficient positive buoyancy to return to the surface.
- The resurfaced Disks are a potential hazard to navigation until recovery operations can be accomplished.

5.3.4 DIRECT DESCENT DISK KEY TECHNICAL ISSUES

- Emplacement Accuracy:
  The Disk concept is intended to descend in a nearly vertical path toward the seafloor. However, the probability and magnitude of the Disk to drift or skating horizontally from its intended path is unknown at this time. This drift condition could be caused by loading variations such as inconsistent filling of cargo bays or variability in bulk specific gravity of the cargo. Computer modelling, simulation and/or physical models could be employed to quantify this characteristic.

- Floater Module Operation:
  The Floater Module concept provides enhanced flexibility over a conventional ship with perhaps a moon pool for launching and recovering Disks. However, this unique Floater Module feature does not come without its own set of issues. The response characteristics of a segmented/multi-connection string of barges in ITB configuration, under open ocean conditions needs to be assessed. Also, the Floater/Disk combination, both loaded and empty, must be assessed for its seaworthiness, as it is intended to be manned during emplacement operations. Recovery of the empty Disks by Floater Modules and recoupling of the Floater Modules with the tug, at sea, is an issue that warrants considerable analysis.

Other technical issues related to the Direct Descent Disk are similar to the Surface Emplacement and ROV Glider concepts. These are:

- Bag Survivability:
  This is exactly the same issue as with Surface Emplacement and the ROV Glider concepts.

- Cargo Bay/Trap Door Design:
  As with Surface Emplacement and the ROV Glider concepts, trap door and cargo bay design are important to prevent bag tearing during emplacement. Also trap door reliability is extremely important since 165 out of 169 cells must release their cargo for the Disk to resurface.

- Throw-Away Transponders:
  Battery powered/multiple channel transponders will be required to assure that the bags are emplaced within the desired disposal site monitoring area.

- Geotextile Bags:
  The cargo cells in the Direct Descent Disk are the smallest of all concepts that use bags, and therefore this concept uses the most bag fabric material. The issue of selecting the appropriate type of bag material and verification that production rates can be met is critical.

5.3.5 DIRECT DESCENT DISK MANUFACTURABILITY/PRODUCIBILITY ASSESSMENT

All elements of the Direct Descent Disk employ materials, processes, and assembly techniques normally utilized for the fabrication of deep ocean capability vehicles. Associated costs are comparable, by direct extrapolation, to anticipated shipyard fabrication costs.

5.4 PIPE RISER

5.4.1 PIPE RISER CONCEPT DESCRIPTION

The Pipe Riser concept is illustrated in Figure 5.4.1-1, with an overall concept process flow diagram illustrated in Figure 5.4.1-2. The Pipe Riser utilizes the principle of gravity flow for the transport of up to 2400 metric tons/hr per discharge line of bulk waste into a designated emplacement site approximately 500 m X 500 m. Utilization of gravity flow results in minimizing the size of the pumping system, estimated in excess of 1200 kW (16,000 hp), that would otherwise be required for moving the large volume of slurryized bulk waste through a riser piping system of 7600 m (25,000 ft). The gravity flow design capability of 2400 metric tons/hr per line is based upon employment of 1.37 m (54 in) outside diameter (OD) X 1.26 m (49.8 in) inside diameter (ID) Driscopipe, a HDPE (high density polyethylene) piping system presently utilized for the pumping of a variety of slurry materials. Gravity flow conditions are initiated by introducing the bulk waste slurry fluid having a bulk specific gravity greater than seawater into the top of the riser, thereby creating a higher static head within the riser discharge line than that of the surrounding seawater. This static head provides the potential energy to raise the discharge flow volume from "zero" to the limit flow volume. The limit flow volume is achieved when the net line losses due to flow equals that of the static head. A diffuser provides means to keep discharge flow velocities to less than 1.5 m/s (5.0 ft/s).

Transporters, carrying approximately 25,000 DWT bulk cargo, arrive from various ports of opportunity along the Atlantic, Gulf and Pacific coasts, after a transit of 1060 km (570 nmi) average distance. The bulk cargo would generally have a high solids content, or bulk specific gravity, in excess of that required to establish safe gravity flow operating conditions, and would require dilution with seawater to establish the desired bulk specific gravity. This dilution seawater is provided from depths of approximately 760 m, mixed with the bulk waste being off-loaded from the transporter, and used to "charge" the discharge lines. Charging of the lines requires approximately 30 minutes to establish the desired bulk specific gravity along the entire line length and achieve full gravity flow conditions.

The following detailed discussion is based upon review and independent assessment by Makai Ocean Engineering, Inc., for determination of the Pipe Riser Catenary shape and induced drag forces acting on the Pipe Riser system. Preliminary assessments indicate that the basic design configuration depicted is a viable approach to operating in water column depths of up to 6100 m (see Hightower et al. 1994, Attachment 5). Further, a review of the upper terminus (Spar Buoy) configuration by JJMA indicates that the basic configuration depicted is a viable operational approach to maintaining a dynamically positioned surface platform above the APWI site (Hightower et al. 1994, Attachment 7, "Riser Top-End" Platform Tradeoff Issues"). Finally, gravity flow characteristics have been reviewed by Hydronautics, Inc., and performance/operational characteristics confirmed.

Pipe Riser Emplacement Employs a Dynamically Positioned Spar Buoy Assembly with Quad Riser System to Emplace ≈ 4800 Tons/Hour Slurrized Bulk Waste

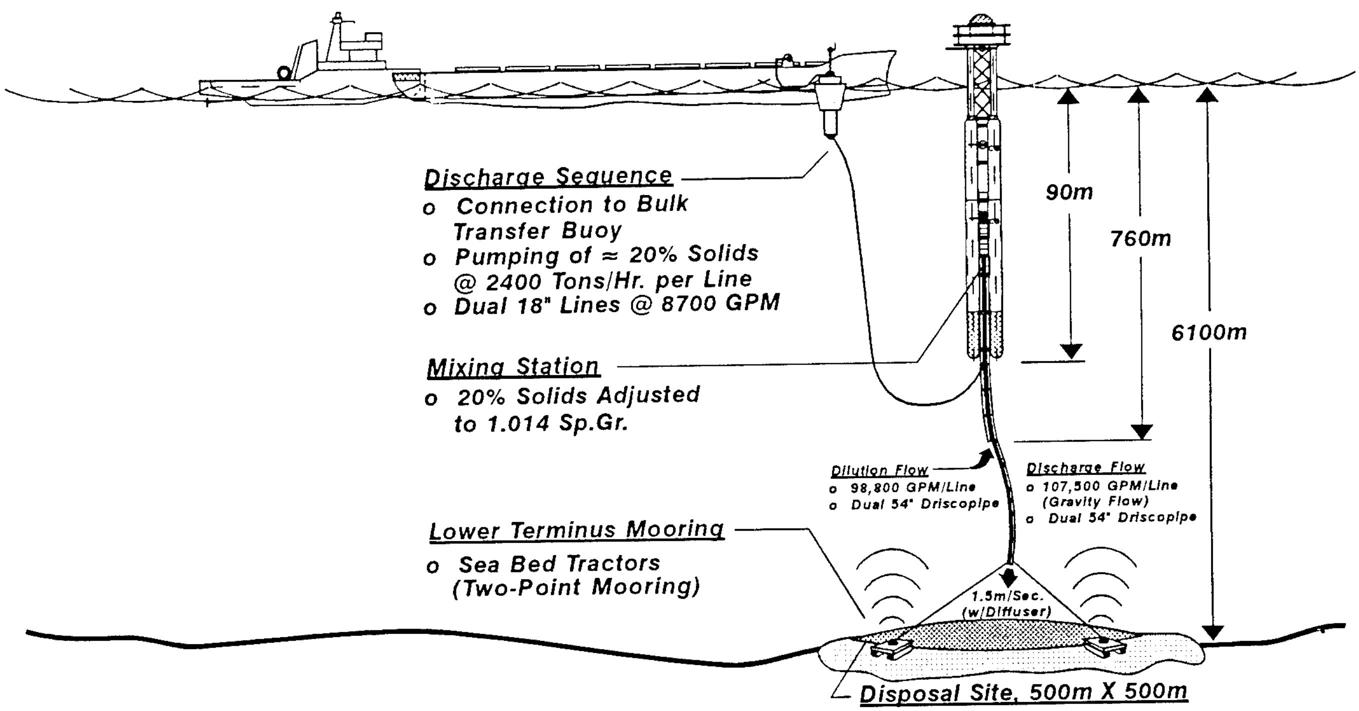


Figure 5.4.1-1
Pipe Riser

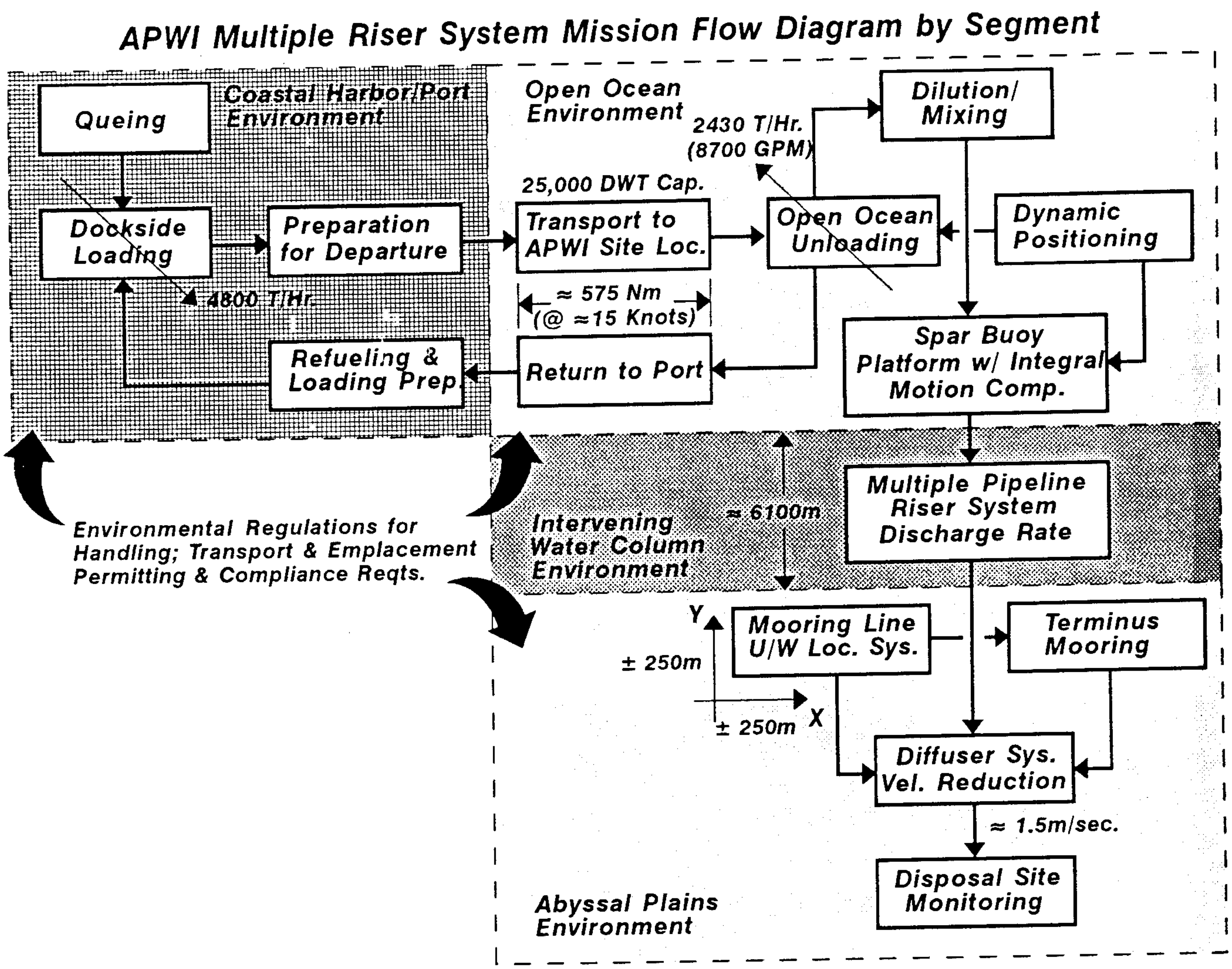


Figure 5.4.1-2
Pipe Riser Process Flow Diagram

The Pipe Riser consists of three major subassemblies:

- The Pipe Riser Assembly consists of two 1.4 m (54 in) OD suction (or dilution) lines approximately 760 m in length, and two 1.4 m (54 in) OD discharge lines approximately 6500 m in length. The discharge line length is dictated by the depth of the APWI site location on the abyssal seafloor and by the prevailing current conditions existing within the intervening water column. A fifth line 0.45 m (18 in) OD approximately 70 m in length is provided at the upper end of the pipe riser to provide a pipeline connection for discharge flow from "off-loading" transporters to a mixing chamber located atop the riser assembly. The Pipe Riser consists of 15.2 m (50 ft) modules designed for on-site final integration into the pipe riser configuration, approximately 6500 m in length. Further details are provided in the following paragraphs.

- A Spar Buoy Upper and Lower Terminus Assembly, with Dynamic Positioning capability, maintains the relative position of the upper section of the Pipe Riser Assembly directly above that of the lower section of the Pipe Riser Assembly. The Lower Terminus of the riser is "moored" to the center of the designated abyssal isolation site, with provision to control the "moored" position within a 10 km x 10 km abyssal site by use of motorized seabed tractors serving as self-movable gravity anchors. The structural connective element between the Upper and the Lower Terminus is the Pipe Riser Assembly, which acts as the "mooring" line for the Spar Buoy, with 2700 kN (600,000 lb) line tension capability. The Spar Buoy Upper Terminus Assembly is approximately 10,000 metric tons (Mg) displacement, and provides features for +/- 37 m (120 ft) motion compensation of the Pipe Riser Assembly. The Spar Buoy provides equivalent (or better) stability characteristics versus that of unmoored dynamically positioned semisubmersible platforms, and provides capability for continuous operation in sea state five conditions. Additionally, as with unmoored semisubmersible platforms, it is capable of surviving sea state eight conditions. The Spar Buoy is designed to be unmanned during periods when transport vessels are not on-site, maintaining its station-keeping functions autonomously. Communication links provide human intervention/monitoring capability from shore-based control sites. Further details are provided in the following paragraphs.

- Dual motorized seabed tractors (mobile gravity anchors), with equivalent clump mass of greater than 145 Mg, provide capability to adjust the moored position of the Pipe Riser. This adjustment in moored position is desirable to facilitate the transfer of the disposal operations to successive 500 m X 500 m sites within the designated 10 km X 10 km site location. This transfer would occur after approximately 4.5 million metric tons of bulk waste have been deposited in a single mound of 500 m diameter by 15.5 m high. Transfer of isolation operations could occur at three month intervals, depending on the total waste volume arriving at the APWI site. The relocation to an adjacent disposal site would require from four to eight hours to accomplish. The clump mass of the seabed tractors/ gravity anchors is dictated by the requirement to provide tractive effort sufficient to overcome induced drag load force components acting on the Pipe Riser at its Lower Terminus. Further details are provided in the following paragraphs.

Pipe Riser Assembly:

The Pipe Riser Assembly is illustrated in Figure 5.4.1-3. This assembly provides the connective link between the seafloor disposal site providing means for gravity flow discharge of up to 4800 Mg/hr slurryized waste into 500 m X 500 m monitored isolation sites. The riser piping system acts as the "mooring cable" between the fixed lower terminus of the riser and that of the upper terminus (or Spar Buoy). The dual 1.4 m (54 in) OD discharge lines provide an equivalent 2700 kN (600,000 lb) tension capability for resisting current drag load force components acting on the riser. These force components, illustrated in Figure 5.4.1-4, are appreciable and reflect worst case loading conditions of currents existing at the APWI sites. Two cases are depicted in this illustration:

with and without clump mass to mitigate effects of the Pipe Riser buoyancy under no flow conditions. Without the additional 65 metric ton clump mass, located at approximately 700 m (2500 ft), the upper portions of the riser could lay on the ocean surface (see Hightower et al. 1994, Attachment 5, "Riser Analysis").

Additional features illustrated in Figure 5.4.1-3 are as follows:

- Capability to utilize the discharge riser lines as "elevator shafts" for passage of rigid packages of containerized waste. The insertion of these packages into the waste mound on the abyssal seafloor might yield an effective capping approach, capping or "sealing" the containerized waste by the overburden bulk waste. The containerized waste packages would be emplaced under highly controlled conditions of low terminal velocity (due to hydrodynamic drag effect between the container and the discharge line) and ability to control the positional location of the lower terminus within precise coordinates of the emplacement site.

- Capability to act as a permanent connective element between the ocean surface and the abyssal seafloor site, such that continuous real-time monitoring of the site could be achieved. This connective element permits the installation of instrumentation at various levels of the water column and on the abyssal seafloor, permitting "wiring" of the site and direct undersea intervention capability via use of ROV mounted work packages for both maintenance of the instrument packages, and for sample collection. As illustrated, the Pipe Riser Assembly provides many desirable mounting interface points for the incorporation of instrumented arrays, electrical power tie-in points, sampling lines, and the support of extended operation undersea intervention packages.

- Capability for capping of the isolation site in a precisely controlled manner. The introduction of clean sediments over a waste mound of approximately 4.5 X 10^6 metric tons, within a 500 m X 500 m isolation site, could be achieved with an exceptionally high degree of emplacement control by use of the positioning capability of the motorized seabed tractors/mobile gravity anchors. These tractors could provide continuous X-Y translation of the lower terminus during capping operations to provide a controlled volume of overburden material per unit seafloor area. This capability would yield a highly uniform capping thickness over the mound--potentially as thin as 0.25 m, or less than 100,000 metric tons of capping material. This volume is less than 2.2% of the bulk waste material contained within the mound.

The illustration in Figure 5.4.1-3 depicts an interconnecting structural element, located at the 15 m (50 ft) joint interval. This element provides increased bending moment, or structural bending rigidity, to the pipe bundle, yielding an effective moment of inertia for the upper section of approximately 0.23 m^4 (553,000 in^4). Additionally, it provides a means to realize increased damping effectiveness versus the dynamic response characteristic of a riser assembly without such feature.

APWI Quad Riser Assembly for Emplacement of >4800 Tons/Hr. Industrial Waste Stream Products @ ≥ 22.5% Solids by Weight

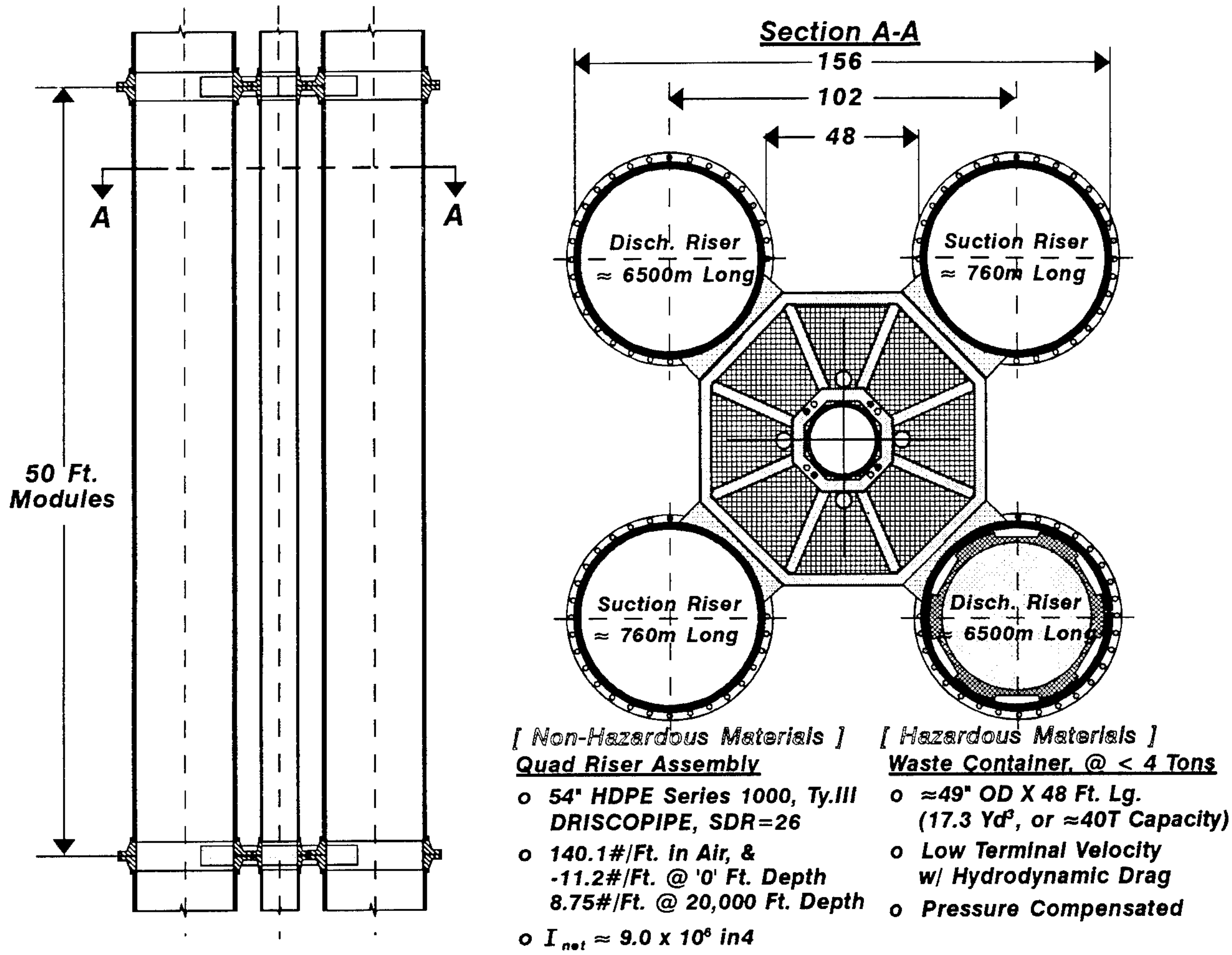


Figure 5.4.1-3
Pipe Riser Assembly

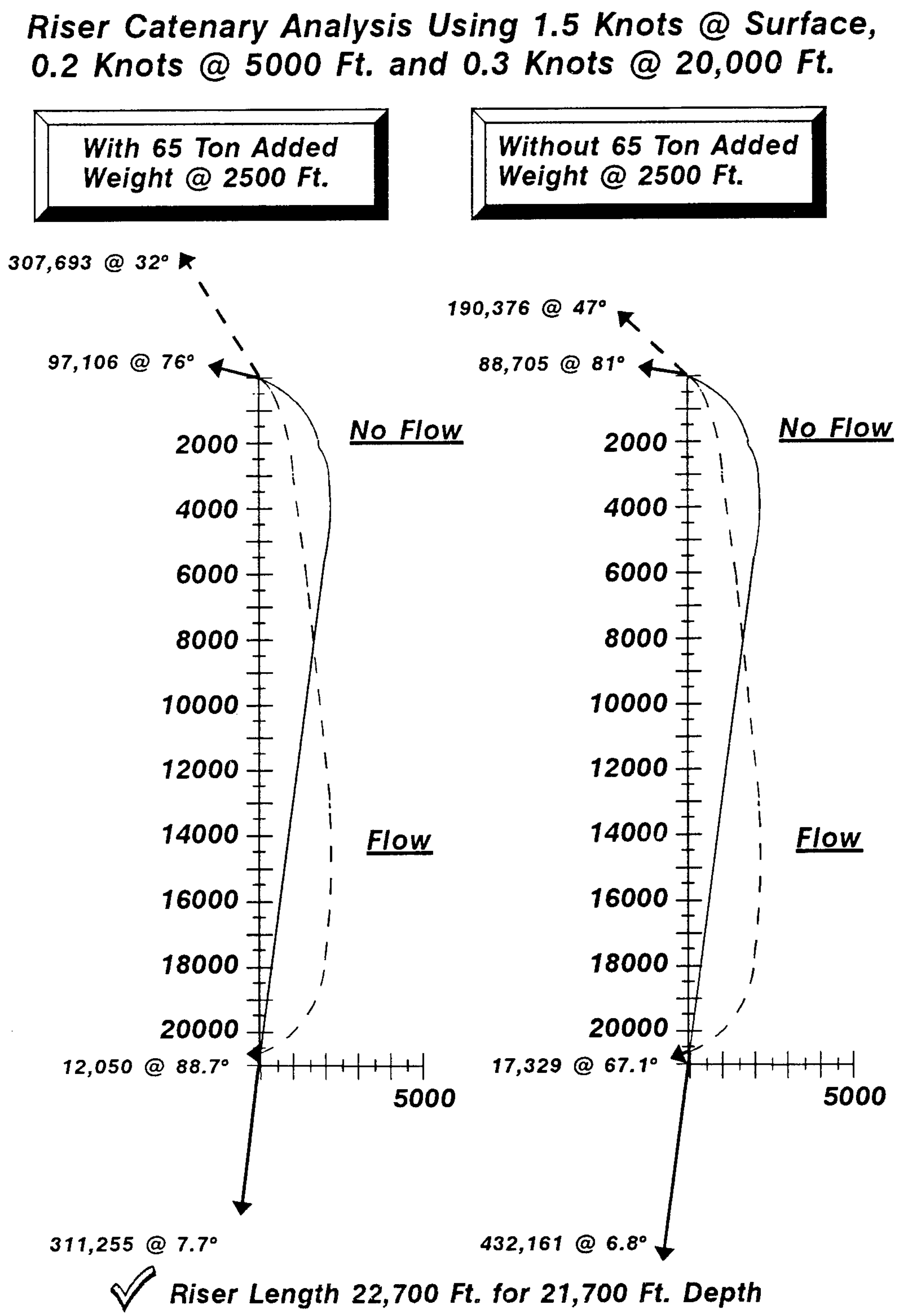


Figure 5.4.1-4
Riser Drag Forces

Figure 5.4.1-5 illustrates the possible magnification of either induced force or displacement amplitudes caused by sea surface conditions. Based upon a single riser line stiffness of approximately 24.6 kN/m (140 lbs/in), a mass of 199 Mg-sec^2/m (11.2 X 10^3 lb-sec^2/in), and damping of approximately 1.21 Mg-sec^2/m (69 lb sec^2/in), we would expect a fundamental resonant frequency of 0.018 Hz, and multiple harmonics up through the 15th to be exhibited. Sea state five conditions could induce riser line stresses equal to that of the manufacturer design limits, and single amplitude displacement response of up to 48.8 m (160 ft). This is unacceptable. Incorporation of platforms at 15 m (50 ft) intervals, with an effective open area of approximately 40% (e.g., use of fiberglass structural grating), yields an increase in damping factor from approximately 0.025 to a value of approximately 0.33. This improvement results in reduction in the magnification response by a factor of approximately 6.5 times. Further improvement, by increase in the effective projected area of the individual platforms and/or the number of platforms provided, rapidly reaches a point of diminishing return and provides little benefit versus the magnitude of any further reduction. A more fruitful means to mitigate dynamic response effects is to incorporate a motion compensation system. Motion compensation of the upper terminus provides the means to de-couple the Pipe Riser Assembly from sea state induced force and displacement excitation amplitudes. The use of both features, additional damping capability and provision for motion compensation, yields the desired robustness in design capability versus the range of environmental conditions existing for a permanent open ocean installation. Motion compensation is described further in the following paragraphs.

On-site assembly of the Pipe Riser is the preferred approach versus assembly in protected coastal water and towing to the installation site. On-site assembly of the 15 m (50 ft) modular elements is facilitated by features integrated into the Spar Buoy, and by the use of typical construction vessels employed for open ocean platform construction projects. Further details are provided in the following paragraphs.

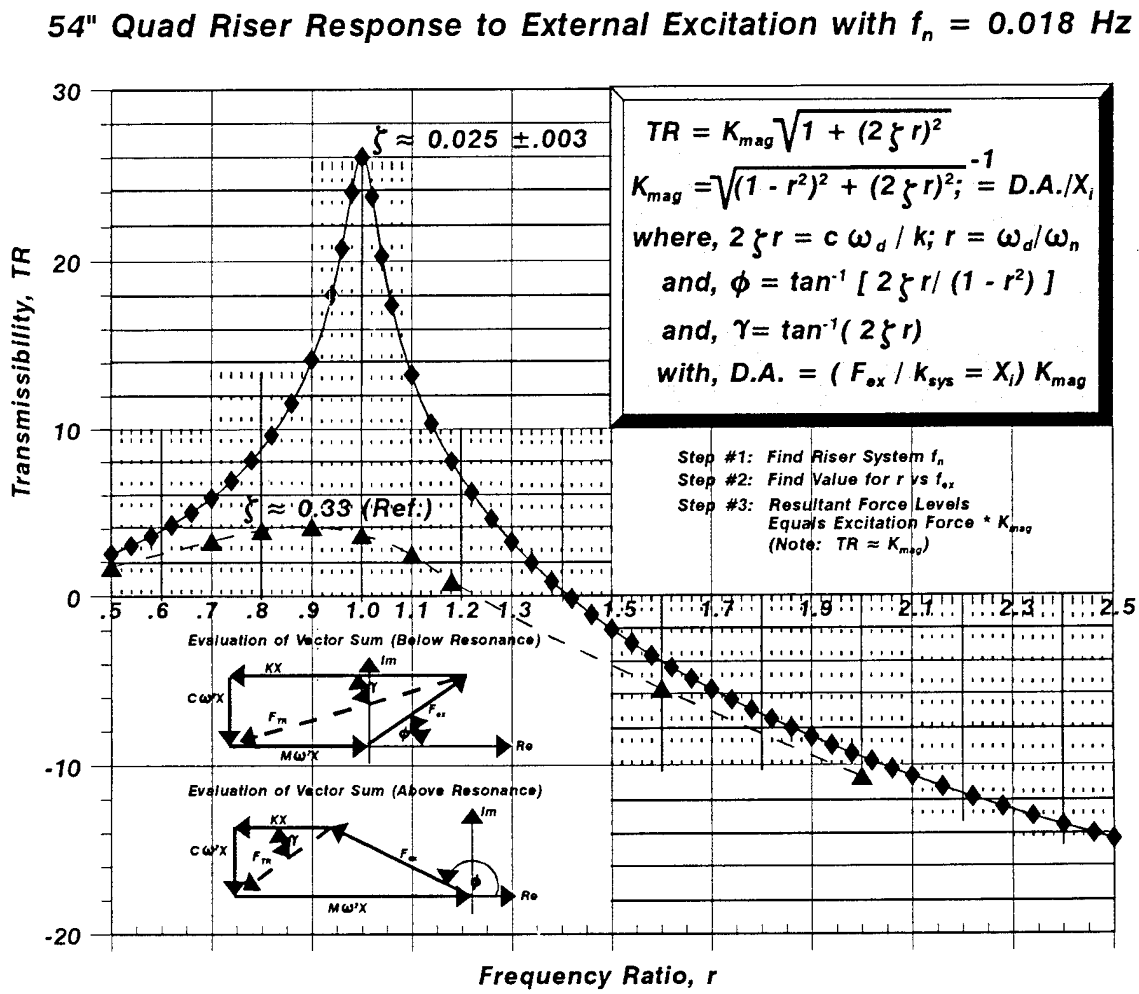


Figure 5.4.1-5
Pipe Riser Dynamic Response Characteristics

Spar Buoy Assembly:

Figure 5.4.1-6 illustrates the Spar Buoy Upper Terminus Assembly. This assembly provides means to dynamically position the Pipe Quad Riser upper section directly over that of the Pipe Riser lower section by use of thrusters. The thrusters would be utilized to position the upper riser section relative to the lower riser section within a watch circle of less then 50 m diameter by providing approximately 1070 kN (240,000 lbs) of thrust. This value is based upon preliminary evaluations contained in Hightower et al. (1994), Attachment 5, "Riser Analysis," and represents a 1.5 X design margin for horizontal drag, due to worst case current conditions existing at the abyssal site water column. This thruster capability would be required during actual emplacement operations of discharging waste through the riser. Under no flow conditions the magnitude of the required thrust would be reduced by approximately 38%. The required thruster power to maintain the Spar Buoy position would therefore vary from approximately 1600 kW to 2500 kW (2100 to 3400 hp), dependent upon whether emplacement operations were being conducted. A set of four 2850 kW (3800 hp) azmuthing thrusters similar to Schottel Model SS4546 Type S assemblies (4 Blade, 3.1 m, controllable pitch) would be employed, with two provided for operational redundancy. Power for the thrusters would be provided by 4200 kW diesel generator sets, similar to Wartsila Vasa 12V32 diesels with 4200 kW Stromberg Generators. Thruster sizing is based upon a Bollard condition of "zero-ahead," with propeller efficiency of approximately 25%, or approximately 156 N (35 lbs) thrust per hp. Fuel oil storage provisions for 2900 bbls (120,000 gal) are provided in the platform support columns.

Power generation capability must be provided 24 hours per day, 365 days per year, in order to maintain the desired watch circle position. Based upon the preliminary analyses provided in Hightower et al. (1994), Attachment 5, "Riser Analysis," minimization of both horizontal and vertical force components may be possible, providing additional design safety margins of greater than 50%. These additional margins would be achieved by the addition of mass at key locations and by providing "excess pipe". The above values may be considered as tentative worst-case values and, based on the limited analyses performed, provide confidence that a riser as described herein will be capable of operation in depths of 6100 m.

Based upon the two extreme loading cases depicted in Figure 5.4.1-4, the constant tension required to support the Pipe Riser Assembly could vary from 577 kN (129,840 lbs) to 1160 kN (260,940 lbs), depending upon whether or not the 65 metric ton clump mass is used. Selection of an appropriate mid-point value of less than 30 metric ton for the clump weight yields a preliminary constant tension value for the motion compensation system 747 kN (168,000 lbs).

As depicted in Figure 5.4.1-6, provision for motion compensation of +/-37 m (120 ft), at constant tension of 747 kN (168,000 lbs), is made as follows. Roller elements are provided between the individual riser lines, spaced relative to one another, and mounted to the structural framing of the legs of the Spar Buoy, over a distance of 73 m (240 ft) from the base. The upper 73 m (240 ft) of the Pipe Riser Assembly would be fitted with stiffened bearing plate elements running longitudinally between the platform structural elements of the riser to provide a continuous roller bearing surface for each of the four sets of roller elements. The resultant configuration provides a captive slider bearing assembly of very low resistance to riser/buoy motions. The constant tension is maintained by a 75 metric ton capacity boom crane tether to the top of the Pipe Riser Assembly, with a hydraulic motor operating in the constant torque (or mooring tension) mode. The higher value of output torque is maintained during actual emplacement operations. Completing the assembly, a mixing chamber with 336 m^3 (12,000 ft^3) capacity and associated buoyancy module, having a net height of approximately 24 m (80 ft), would be mounted on top of the Pipe Riser. The mixing chamber would connect the suction (dilution) lines to the inlet of the discharge lines and connect to the slurry feed lines running from the transporter connection points. The size of the mixing chamber is predicated upon the necessity to provide surge volume, such that water-hammer effects are mitigated. Water-hammer effects could induce pressure transients of greater than 2.5 times the pipeline

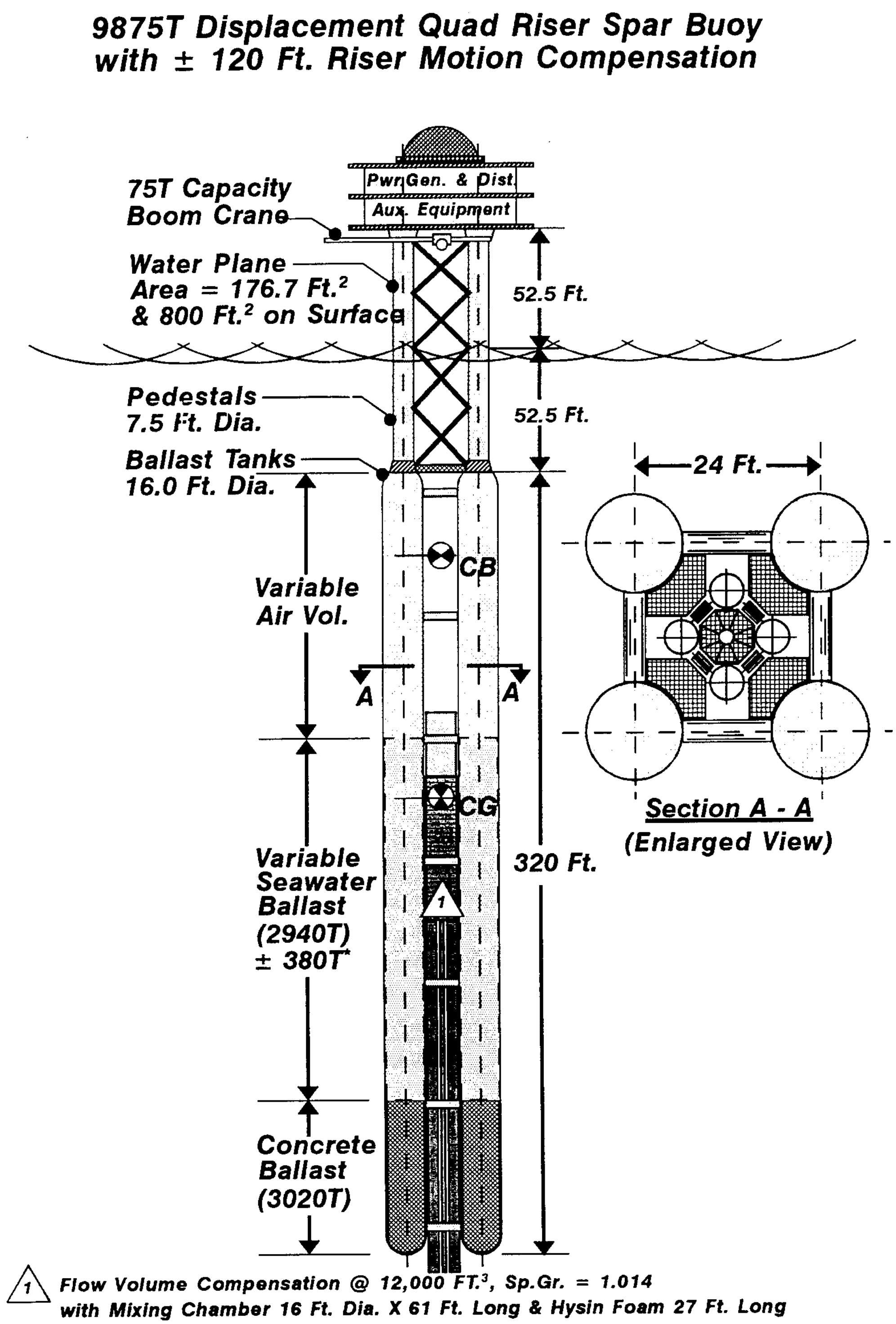


Figure 5.4.1-6
Pipe Riser Assembly with Motion Compensation Provision

design stresses. Water-hammer would occur if flow momentum transients occur over less than 48 seconds duration (critical time constant). This time period could easily be realized with inadvertent loss of dilution flow due the pump shutdown, in-line valving closure/opening, etc. The surge volume provides capability to "bleed-down" the system over a period greater than 48 seconds. The mixing chamber flow volumes would be approximately as follows:

- Dilution flow is estimated to be 420 kiloliters/min (98,800 gpm) per suction line, provided from 760 m depths. Note that this source depth is desirable for two reasons: (1) seawater temperature is very close to that existing at abyssal depths, therefore emplaced material is "thermally habituated" and thermal convective plume effects significantly reduced; and (2) drawing from the biologically non-productive ocean layer reduces the amount of additional food source available to benthic organisms at the isolation site.

- Discharge flow is estimated to be 457 kiloliters/min (107,500 gpm), based upon a transporter off-loading flow volume of approximately 33 m^3/min (8700 gpmn), of a slurry of 1.25 specific gravity. Note that this bulk specific gravity is equivalent to a dry solids concentration of approximately 22.5%, or 552 metric tons/hr dry solids. The net off-loading wet metric tons/hr would be 2430 tons/hr per riser line, or a maximum possible off-loading rate of 4800 metric tons/hr. Figures 5.4.1-7 and 5.4.1-8 are provided for reference purposes to describe the technique employed for determination of the percentage of solids versus specific gravity, and to quantify riser line losses versus flow volume. The ratio of the above flow volumes reflects a solution for one bulk waste case, wherein the input flow to the top of the discharge riser provides the desired slurry bulk specific gravity of 1.014.

The required pumping horsepower would be broken down as follows: (1) suction flow at approximately 670 kW (900 hp) per line and, (2) transporter off-loading flow at approximately 93.3 kW (125 hp) per line, assuming a 0.46 m (18 in) diameter feed line of 240 m (800 ft) length, connecting the transporter to the mixing tank. Note that this length feed line is based upon the need to route the line beneath the Spar Buoy and up the centerline of the Pipe Riser to the top mounted mixing tank. This routing is essential to permit relative motion of the Pipe Riser by +/-37 m (120 ft) with respect to that of the Spar Buoy structural framework.

Maintaining the bulk specific gravity to a maximum value of approximately 1.014 is based upon recognizing that the induced flow drag effect of moving such large volumes of slurry rapidly approaches a point in which the pipeline tensile stresses reach the design stress limits. Since the Driscopipe has a design stress limit of 5.6 MPa (800 psi), the flow velocity must be kept to less than 5.7 m/s (18.8 ft/s). Additionally, at this value, if gravity flow were to be abruptly halted due to a flow system failure, the static head would induce pipeline hoop stresses 1.8 times greater than design stress limits. Relief valving must be provided to assure that hoop stresses cannot exceed design limits, and features to incorporate bidirectional cross-port relief valves at intervals along the discharge line must be provided. Finally, inadvertent termination of dilution of slurry flows could cause the fluid within the discharge line to reach an equilibrium condition wherein the liquid level would drop, creating a condition of high external hydrostatic pressures being greater than design limits. The pipeline would collapse. Consequently, bypass suction valving must be provided at intervals along the upper portion of the discharge lines to provide the necessary flow volume created by the change in liquid level.

The resultant Spar Buoy Upper Terminus, depicted in Figure 5.4.1-6, is configured to provide a high degree of stability for operation in the open ocean environment. Sea state five wind and wave conditions would result in less then 1.5 degree roll, with survivability (only) for withstanding 100 year storm conditions, 32 m (105 ft) waves, 65 m/s (127 knot) winds and 1.3 m/s (2.5 knot) surface currents, with reduced ballast.

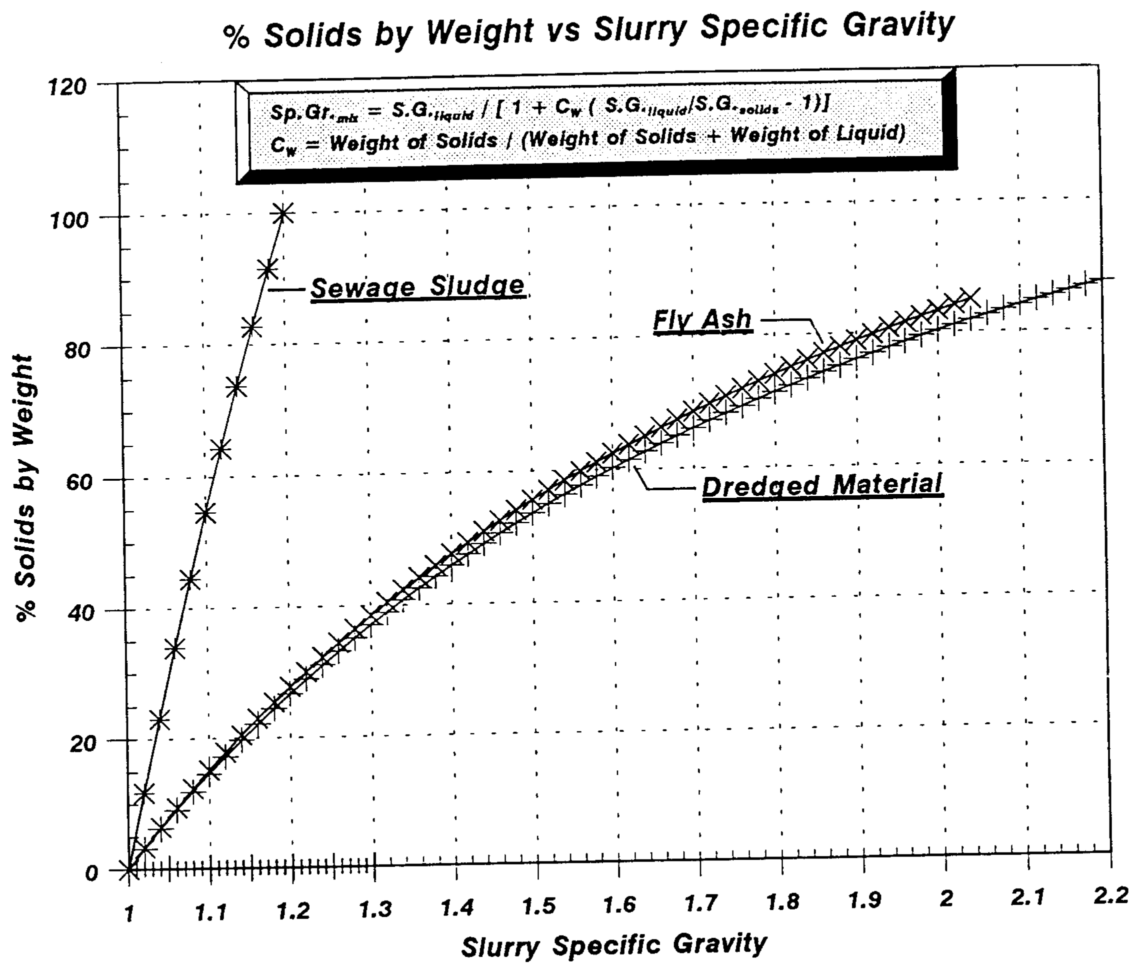


Figure 5.4.1-7
Percent Solids by Weight versus Slurry Specific Gravity

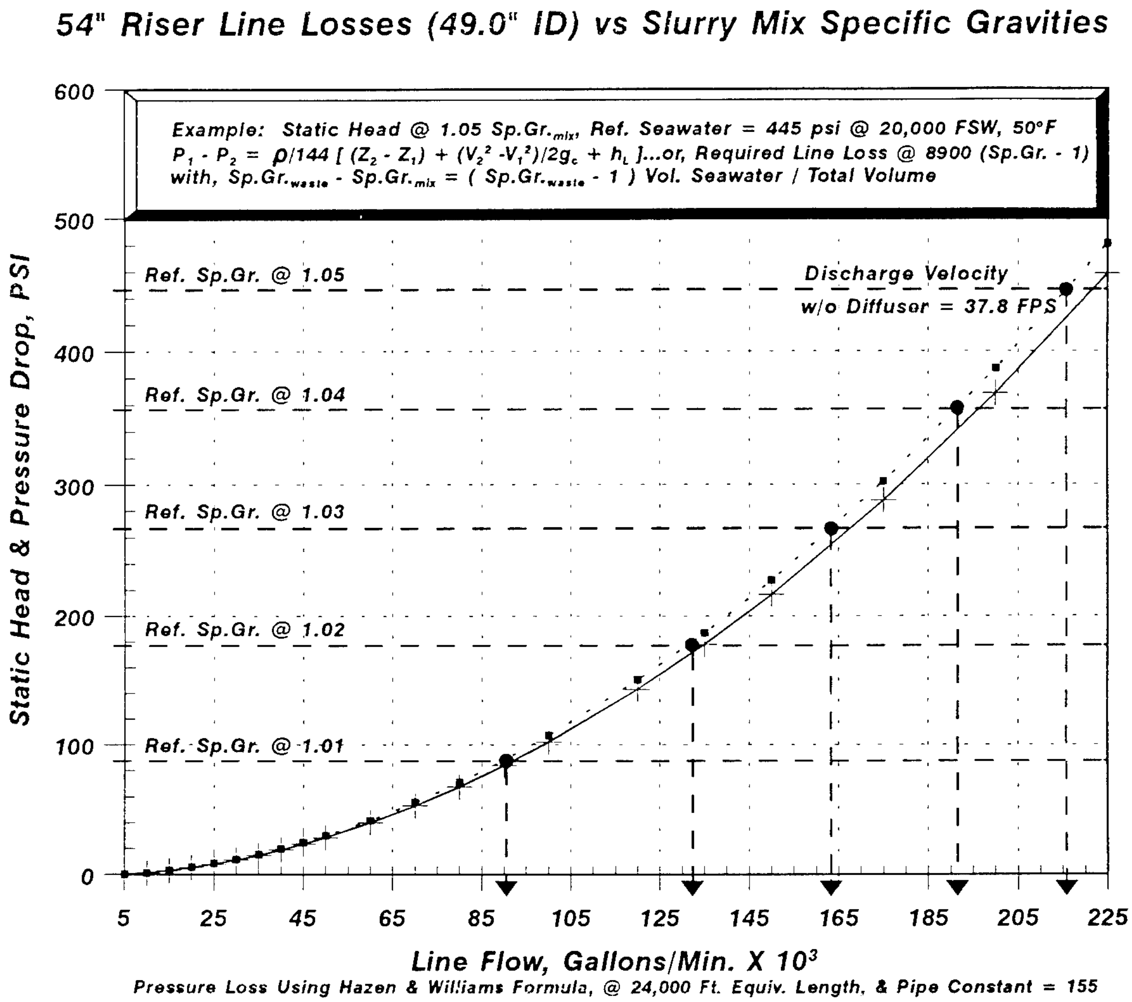


Figure 5.4.1-8
Riser Line Losses

The Spar Buoy Assembly is intended to be an unmanned platform, providing remote human interface control, and fully automatic/autonomous operation during non-operational periods. The arrival of a transport vessel permits the vessel's crew to power up relevant elements of the Riser and Spar Buoy, confirm operational status, and directly monitor the discharge operation. When off-loading is completed, the crew powers down these elements and departs. During the period of bulk waste unloading, the crew must also check the status of fuel for the power generation system, and supply fuel as required. Periodically, maintenance specialists may be transported to the facility to perform specific maintenance activities.

It is envisioned that the Spar Buoy Assembly would be towed to the site in two increments. The first increment would be the preassembled base, consisting of the four legs of the platform. The second increment would be the machinery decks, a two level structure containing the operational machinery, power generation equipment, control systems, and all auxiliaries. The preassembled base would be erected using conventional controlled flooding techniques to achieve a vertical orientation, at which point concrete ballast would be added to establish platform stability. Additional seawater ballast would then be added to lower the upper legs (waterplane) to near the surface. The machinery decks would then be integrated with the lower portion. A derrick barge, similar to Global Industries Ltd. DB-2 or DB-3, or OPI International, Inc. DB#2, would place the preassembled 160 metric ton machinery decks onto the upper superstructure. Outfitting would then be completed, and the facility activated, with seawater ballast being removed to raise the Spar Buoy to a height above the ocean surface of approximately 32 m (105 ft). This would expose the working platform for assembly operations for the Pipe Riser Assembly. The 75 metric ton capacity boom crane would be utilized to off-load preassembled 15 m (50 ft) modules from a transport, commencing with the lower riser piping first, and assembling the riser by a process of mating, fastening, lowering one section and engaging of a hydraulically actuated gripper. The process is repeated until the entire riser is completely assembled. The final step involves integration of the mixing chamber with associated flotation element. Undersea operation will be required for the connection of the transporter slurry feed line to the riser assembly, and to make connection to the transfer buoy.

Motorized Seabed Tractors:

Figure 5.4.1-9 illustrates the Spar Buoy Lower Terminus Mooring Platform (Movable Anchor) Subsystem. The main functions of the subsystem are performed by two deep sea tractors. The tractors are part of a two point mooring system and are essentially self-positionable anchors. They are attached to the riser by a mooring ring and 3.6 MN (800,000 lb) rated synthetic line. The combination of two tractors provides redundancy and load sharing. The use of a two point moor also minimizes snap loads which would be a concern with a single point moor and subsequent riser motion caused by current directional changes. In order to reduce overall tensions in the mooring lines, the scope is designed to be a maximum of 3:1. This scope and line tension is maintained by relative positioning of each tractor. Terminus repositioning typically would occur on the order of once every three months.

The main elements of the Terminus Positioning Subsystem are described below:

- Two Seabed Tractors, whose overall size is approximately 12.2 m X 12.2 m (40 ft X 40 ft) X 3 m (10 ft) high, wet weight of 145 metric tons, with tractive force capability of greater than 750 kN (168,600 lbs). Motive power for each tractor is provided by eight each LSHT direct hydraulic drive motors, supplied by redundant Hydraulic Power Units (HPUs), providing 0.15 m/s (0.5 ft/s) velocity (variable speed) capability at less than 149.2 kW (200 hp). Power is supplied from the surface, through an umbilical power cable routed down the riser assembly, along the tethers to the slip ring assembly mounted at the centerline of the turret. All elements are pressure compensated, with all subsystem elements (HPUs; Main Hydraulic Drive Motors; etc.) mounted to facilitate direct access by undersea intervention ROV work packages, for removal and replacement as required.

Quad Riser "Motorized" Abyssal Plains Mooring Platform Configuration
Wet Weight 145T at < 3.5 PSI Soil Loading; 30 FPM Vel. @ < 200 SHP

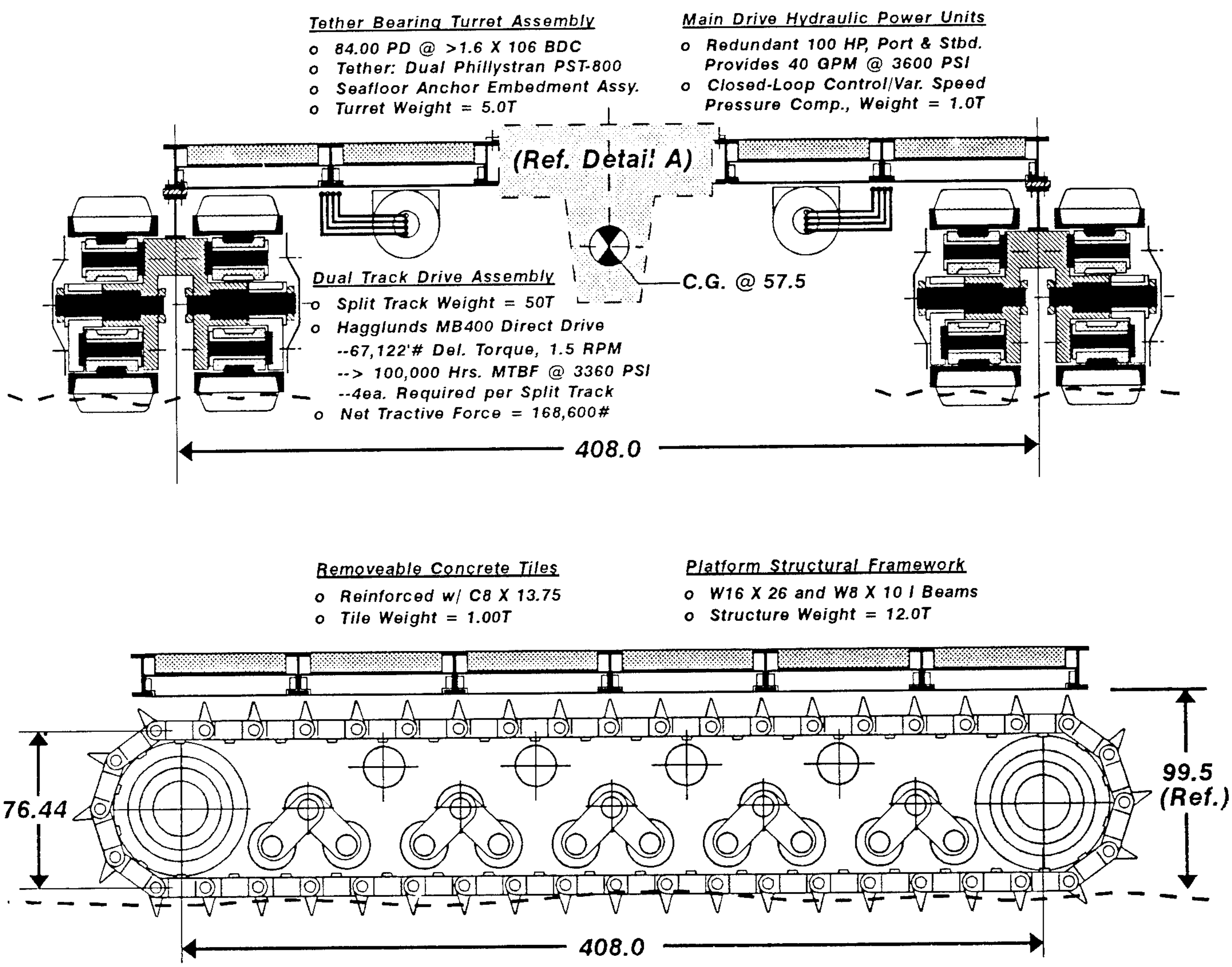


Figure 5.4.1-9
Spar Buoy Lower Terminus Mooring Platform

Comparison of the proposed Seabed Tractors to existing technology, similar to the D500 Sea Crab, provides means to establish scaling factors to the larger size required for the APWI application. The D500 is a 6-7 m (20-23 ft) long X 2.2 m (7.2 ft) wide X 1.2 m (3.9 ft) high tandem unit, with wet weight of 3.4 metric tons, providing 30 kN (6700 lb) tractive force (87% of wet weight) at 0 to 2 m/s (0 to 6.6 ft/s). Loaded seafloor ground contact pressure is approximately 14 kPa (2.0 psi). The proposed Seabed Tractor/Mobile Anchor is approximately 43 times larger in size, providing approximately 70 times the tractive force at 13.3 times reduced velocity. The tractive force is 52% of wet weight. Ground contact pressure is 1.75 times that of the D500. To maintain similitude between the APWI tractors and the D500, either the tractor weight could be reduced to approximately 86 metric tons or the track bearing area be increased by 1.75 times. Note that the greater mass would probably be required to restrain vertical component drag forces acting on the Pipe Riser Assembly (Figures 5.4.1-1 to 5.4.1-4); therefore, increasing the track bearing area appears to be the more appropriate choice.

Provisions are included for use of a hydraulically embedded anchor (HEA) to augment anchor system holding capacity when stationary, and/or use of an optional vertically oriented auger screw assembly. A third alternative is use of ram-actuated pawl lock engagement of each track. The tractor could be driven to align its longitudinal axis with that of the tether to maximize seafloor gripping or holding capacity through the embedded track teeth, assuming that seafloor sediment exhibits sufficient shear strength. Seafloor soil properties dictate the nature of the desired solution.

Appendix C, per NRL-SSC Code 7432, provides a summary of representative measured data on seafloor sediment shear and bearing strength. These data indicate (for 18 core samples) that for the Western North Atlantic water depths of 2000-5800 m, shear strengths of 2.2 kPa (0.32 psi) and bearing strength of approximately 18 kPa (2.6 psi) can be expected.

- Umbilical cables, with power, data, and command lines, are maintained under zero tension by supporting them from the mooring line(s).

- Mooring lines, similar to Phillystran PST-800 are 67 mm (2.75 in) in diameter, 305 m long with a 3600 kN (800,000 lb) breaking strength. This Aramid-fibered rope has a 7-strand construction with a braided polyester jacket. The factor-of-safety for the mooring lines is 3.25 for the operating condition of no emplacement flow, with resultant vertical tension of 1400 kN (311,000 lbs) 7.8° from the vertical, and with 65 metric tons of added weight located at 760 m depth. Assuming that worst-case scenarios have been assessed within the context of conceptual validation (only) it is reasonable to expect design optimization to result in significantly increasing the factor-of-safety, potentially as high a 10:1. Additionally, if the optimization process is not as fruitful as anticipated, the simple alternative is to increase the size of the line from 67 mm (2.75 in) to 108 mm (4.25 in).

The method of emplacement, for either single or dual tractor mooring capability, would be the same, employing a "list-to-launch" of a small special purpose ITB. The Seabed Tractors would be fitted with expendable drag brake, similar to that disclosed in US Patent # 4,165,707, Valent et al., for a "High Lateral Load Capacity Free-Fall Deadweight Anchor," 28 August 1979. An alternative approach is to employ a derrick barge to lower the individual tractors on a pipe string. This approach would require a significantly longer time to accomplish (approximately six days). Capability presently exists for lowering a 360 metric ton (800,000 lb) anchor component. Using this approach, two derrick barges would provide simultaneous lowering of the tractors, with that of the Pipe Riser Installation. The tractors would be connected to the lower terminus at the surface, and act as clump weights for the Pipe Riser Assembly during its assembly/installation on the Spar Buoy platform.

5.4.2 PIPE RISER OPERATIONAL DESCRIPTION

The riser control system oversees and/or controls all aspects of the emplacement operation. This includes pump control and power supply, valve control (not including riser safety valves which are spring or pilot actuated), riser motion compensation system and tensioner equipment. The control system provides all command and data processing for the riser safety and status instrumentation.

There are two active control systems during emplacement operation. The primary system resides within the surface platform and has full control of all riser control functions. A fully redundant system resides on the waste transport vessel with personnel overseeing operations with capability of overriding any command.

The control system monitors waste off-loading rates and density. Based on these parameters, the sea water intake flow rates are varied to provide a slurry bulk specific gravity of approximately 1.014 (with respect to sea water). Typically, the waste is diluted in-line so that it is emplaced without delay and need for any on-site storage. As the slurry proceeds down the riser, the flow rate, pressure, and density are measured at approximately 300 m (1000 ft) intervals. Assuming a flow rate of 5.5 m/s (18 f/s), this allows flow readings of the same mass at approximately every 56 seconds. If conditions of high pressure, high density or high flow velocity are measured, the water intake rate is increased and/or the waste off-loading rate is decreased until the pressure, density, or flow rate reading is within bounds.

The primary control system is located within watertight compartments located at the top of the riser assembly. It includes dual 4200 kW primary power generation, a 1500 kW power source for suction pumps, and 25 kW-hr uninterruptable power supply and dual 250 kW power sources for related auxiliary systems (trim and ballast transfer pumps; fuel transfer; bilge, etc.). Further redundancy in emergency power generation might also be provided by a 1 to 5 kW solar cell system for powering of emergency systems/warning beacons/alarms, etc. Most control functions are performed during emplacement operations, which are expected to be occurring 65% to 90% of the time, based upon sea state conditions impact on operational availability for the specific isolation site. During non-emplacement periods, the system is in a "low power" mode with only thrusters and instrumentation operating.

An operating scenario for unloading operations is described as follows:

- Bulk Waste Transporter arrives on-site, and positions to maintain heading into the wind alongside the transfer buoy. Boom crane lifts transfer buoy line pendant to connect to discharge line(s) from the individual cargo bays. Vessel maintains station-keeping with respect to both the transfer buoy and the Spar Buoy, using its dynamic positioning thrusters. Line connection integrity checked prior to next step.

- Vessel crew powers up Spar Buoy dilution pump(s), while simultaneously powering up the slurry transfer pumps, thereby filling the mixing chamber. The proportion of bulk slurry to dilution seawater is adjusted to realize a mixing chamber bulk specific gravity of <1.014 (with respect to seawater). Once the mixing chamber is filled to approximately 90% capacity, the isolation valve to the discharge line(s) is slowly opened, and buildup in discharge flow volume is initiated over the next 20+ minutes.

- Transport vessel off-loading proceeds at the rate of approximately 2400 metric tons/hr if using a single discharge line, or approximately 4800 metric tons/hr for two. Assuming 4800 metric tons/hr, the vessel could be unloaded in approximately 5.2 hours.

- Vessel crew powers down the Spar Buoy dilution pump(s), disconnects from the transfer buoy pendant line, and prepares for return to port.

The operational timeline for the Pipe Riser concept is shown in Figure 5.4.2-1.

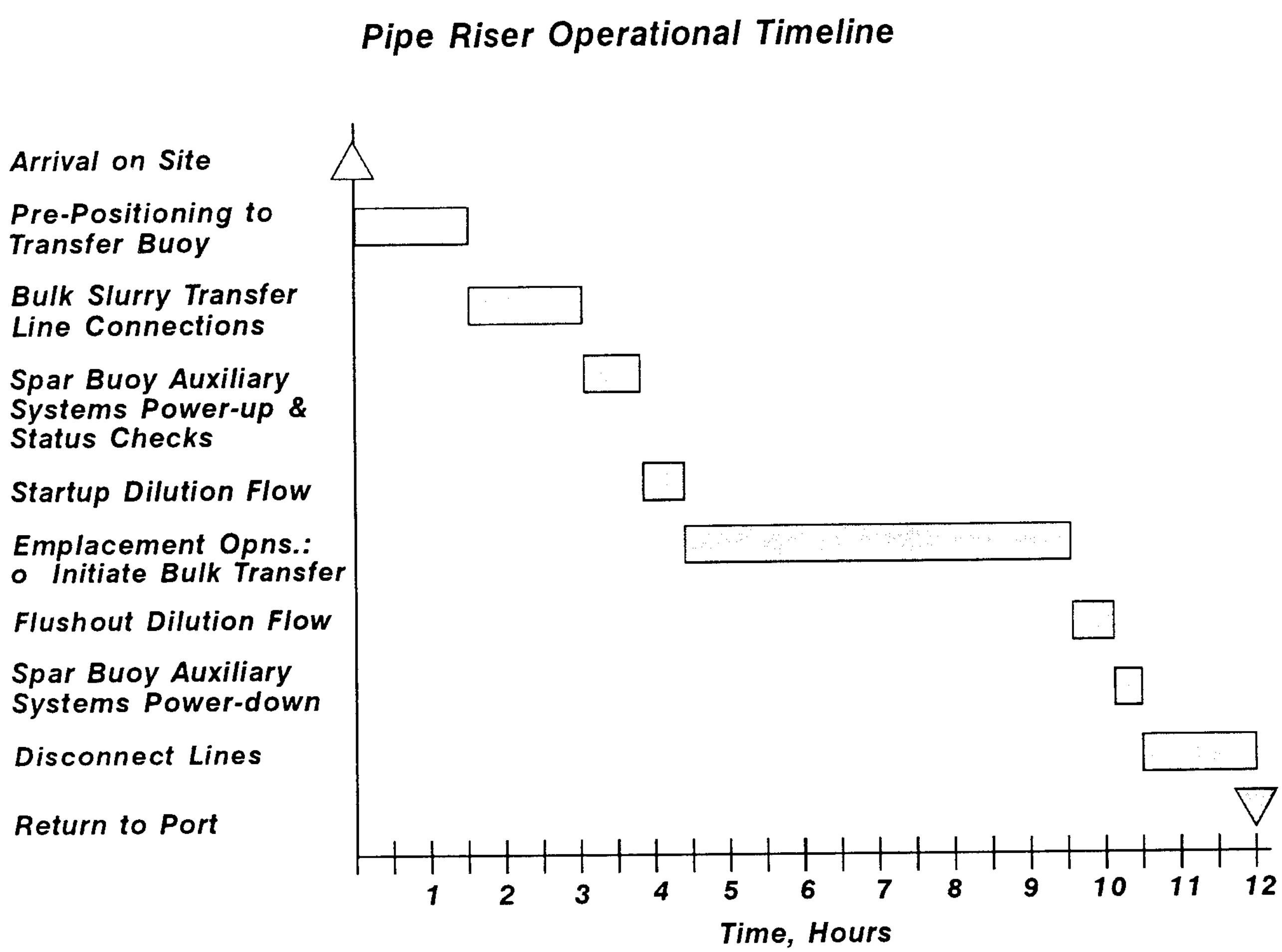


Figure 5.4.2-1
Pipe Riser Operational Timeline

5.4.3 PIPE RISER SUMMARY OF ADVANTAGES/DISADVANTAGES

There are several important advantages that can be attributed to the general riser concept. These are:

- Isolation Site Mound Generation:
  The capability to positively position the lower terminus provides assurance that the waste emplacement process will occur within precise locations capable of being readily monitored (Figures 5.4.3-1 and 5.4.3-2). Additionally, due to the very low (less than 1.5 m/s (5.0 ft/s)) discharge velocity, plume generation will be minimized. Eddy kinetic effects caused by the discharge flow "jet" will be dissipated by diffuser action. Finally, because of the large volume of slurry water used for dilution of the bulk waste to reduce its bulk specific gravity to the desired levels for gravity flow, thermal habituation will assure that any thermal convective plume effects are also minimized. The estimated temperature difference of the discharge stream, at approximately 11.3:1 ratio, would be approximately 1°C (2°F).

- Majority of waste is isolated by subsequently emplaced layers:
  - Self-capping (88% isolated by top 1 meter)
  - Potential to cap waste with clean material (small volume)

  Although uncontained, 88% of the waste is isolated from the abyssal environment by the top one meter layer. For typical waste operations, clean sediments could be used to isolate contaminated wastes by capping. The ability to cap provides some unique possibilities for the isolation of waste.

- Efficient use of isolation site:
  The Pipe Riser provides means for the direct mounting of monitoring instrumentation. These instruments can be powered to receive and transmit information using the existing riser umbilicals. Also, this instrumentation would not require independent relocation since it would be relocated along with the riser equipment. This equipment could be located at the lower terminus, on the crawlers, where they could provide a local monitoring capability.

  The riser has the ability to maximize the amount of waste that can be emplaced in the isolation site. Current estimates show that the riser can emplace on the order of 1.8 billion metric tons of waste at a single 10 km X 10 km site or 4.5 million metric tons in a 500 m X 500 m emplacement site.

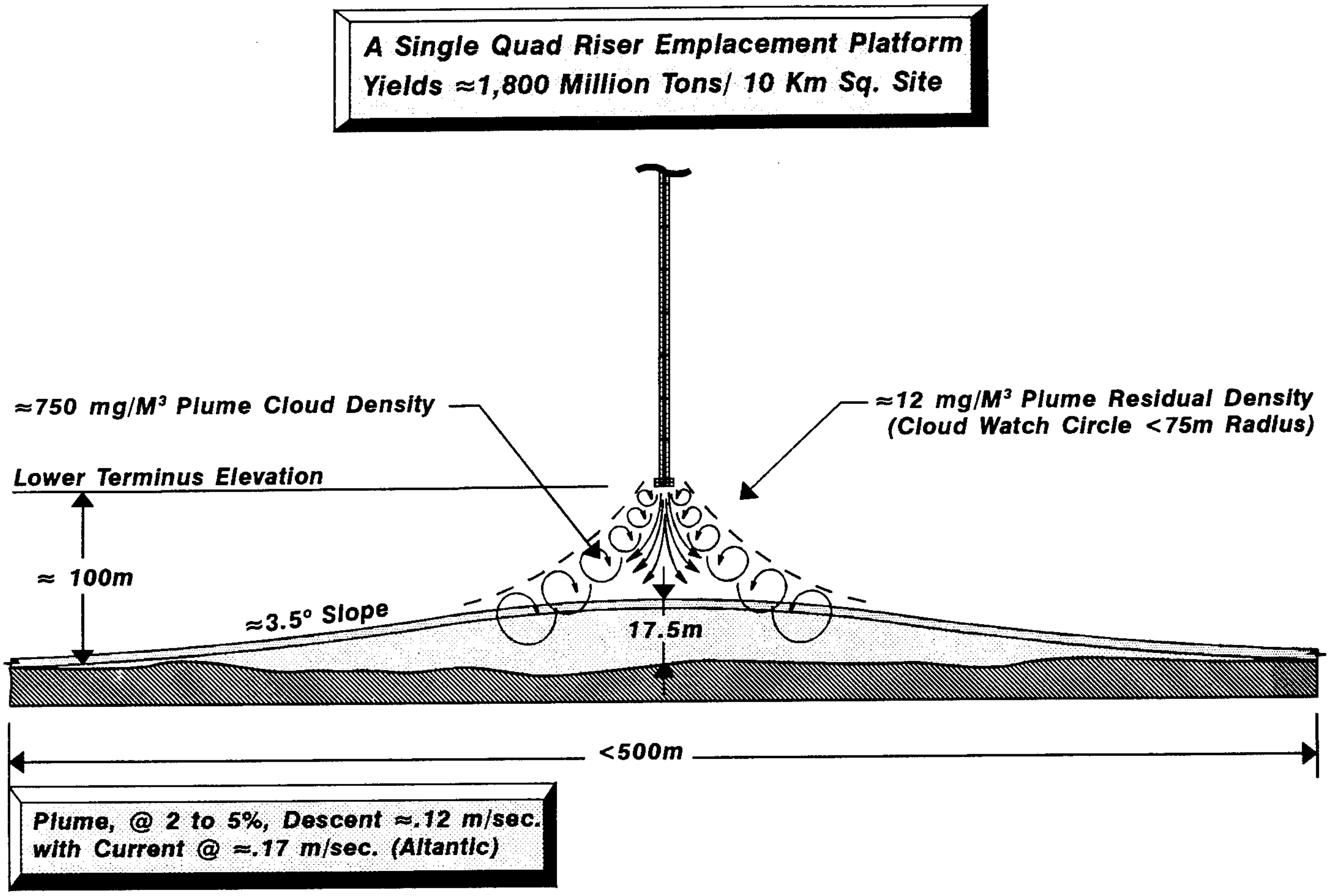


Figure 5.4.3-1
Abyssal Seafloor Isolation Site with Plume

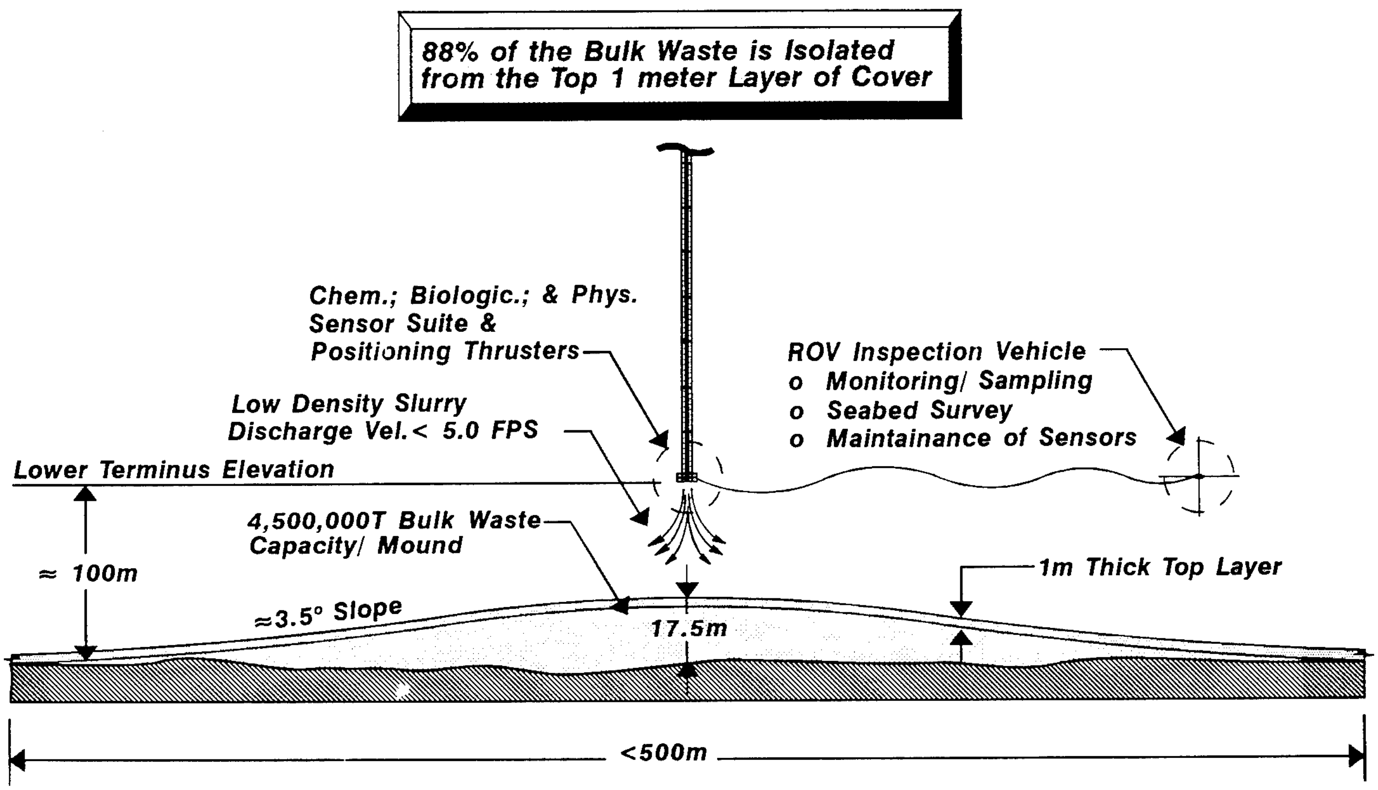


Figure 5.4.3-2
Mound Characteristics

The disadvantages of the Pipe Riser concept are as follows:

- The system will require a high degree of redundancy for all critical systems to mitigate the potential for multiple, potentially catastrophic failure modes. All systems must possess fail-safe features and must be amenable to system health monitoring (i.e., all systems must possess capability to anticipate impending failure(s)). The control system and associated communication links must also be redundant, providing virtually 100% operational availability. Since the Pipe Riser services several cargo vessels, its operational availability requirement is the highest of all APWI concepts. Additionally, it must be a permanent on-site system capable of surviving all weather conditions.

- The Pipe Riser is a formidable technical and operational challenge, employing component sizes for the Pipe Riser Assembly, Seabed Tractor, and waste handling pumping systems approximately 20 times greater than existing state-of-the-art.

- Maintenance of the system requires remote intervention at great depths. Although Remotely Operated Vehicles (ROVs) exist which are capable of operations at these depths, these operations are complex and very difficult using present-day deployment techniques and work package capability. Significant engineering effort will be required to provide the desired level of operational ease and intervention capability necessary to maintain the system in a reliable and effective manner.

5.4.4 PIPE RISER KEY TECHNICAL ISSUES

The Pipe Riser concept is comprised of a number of elements, all of which present formidable technical and operational challenges. Comparison of the system scale, versus that of previous similar systems, indicates a greater than 6 to 40 times increase in size. Indications are very high, based upon the preliminary concept definition provided, that potentially catastrophic failure modes will exist. Capability to provide the necessary reliability to mitigate these failure modes will only be realized by use of critical component redundancy. Additionally, incorporation of "large" design factors of safety will be required vis-a-vis operating conditions (to minimize operational stresses) in order to achieve the minimum desired level of component reliability. Finally, employment of health monitoring techniques, to anticipate incipient failures, will be mandatory for assuring the operational availability of the unmanned system. The Pipe Riser control system must be capable of establishing failsafe shutdown conditions autonomously, as capability to maintain the system is severely limited. This limitation is due to the open ocean location and the time required to transport repair personnel and spare parts. The use of scheduled maintenance will therefore be critical in the establishment of overall system reliability, by providing capability to fix "potential" problems before they become major problems.

The Pipe Riser presents unique problems, versus the other APWI concepts, with respect to scalability. Building a scale model doesn't translate, when one considers the water column dimension versus that of the associated hardware sizes. The designer must rely on simulation/modeling tools to determine the relevant loading response characteristics of specific elements. These tools must rely on the accuracy of the modeling parameters, and be applicable to multiple degrees of freedom response evaluations. Technical issues expected to be resolved during a preliminary design phase are as follows:

- Motion compensation of +/-37 m (+/-120 ft), at approximately 60% loads will have to be accomplished. This is approximately six times the travel distance of existing systems, such as the Vetco MC400-20-D, used for drillstring motion compensation. Dynamic simulation of the system, to assess simulation runs will dictate the compensations to be considered for use in the Pipe Riser system.

- Slurry dilution/mixing and associated control system evaluation should be modeled using a simulation language similar to CSSL-IV. Performance evaluations should be conducted for all anticipated operational conditions. Optimization of the associated control/feedback strategy would be established by a process of iteration.

- The suction pumping system requires that dual 850 hp pumps be operated continuously at a working depth of 760 m to provide approximately 420 kiloliters/min (98,800 gpm) discharge flow. Employment of pressure-compensated housings for the electric drive motors, with the associated pumps, is the desired approach, with the pump impeller shaft using a pressure-compensated hydrostatic suspension system and conventional Sealol shaft seals. Undersea intervention features must be established to facilitate maintenance capability.

- Failsafe Modes/Control System/Redundancy must be thoroughly analyzed to proceed with this concept. Deployment and long term reliability are two critical issues.

- Seafloor tractor's performance capability rests primarily with the abyssal seafloor site sediment properties. The design of the seafloor tractor's load bearing area versus weight in seawater, and selection of tracked versus screw drive, is contingent upon completion of a detailed site survey.

  Seafloor tractor's scalability on the order of 50 times larger than conventional tractors is a major issue. Deployment and long term reliability are two critical issues.

5.4.5 PIPE RISER MANUFACTURABILITY/PRODUCIBILITY ASSESSMENT

All elements of the Pipe Riser employ materials, processes, and assembly techniques normally utilized for the fabrication of both open and deep ocean capability vehicles. Associated costs are comparable, by direct extrapolation, to anticipated shipyard fabrication costs.

5.5 TETHERED CONTAINER

5.5.1 TETHERED CONTAINER CONCEPT DESCRIPTION

The Tethered Container Concept is shown in Figure 5.5.1-1 and employs a waste container that is lowered by a winch and tether to the seafloor from the surface support vessel and recovered after releasing its contents. The main elements of the concept are the waste container, tether, handling system, and the vessel. Each of these elements are integral to the success of the concept. Figure 5.5.1-2 depicts the process flow diagram of the tethered container.

The maximized system yields 250 metric tons (Mg) of waste material emplaced every 1.05 hours or 240 Mg/hr at abyssal depths. The 240 Mg/hr is based on the following time calculations and estimates:

Given:

Container Load:	190 m^3 (250 yd^3) at 1.25 bulk S. G.
Depth:	6100 m (20,000 ft) sea water
Rate of ascent/decent:	5.1 m/s (500 ft/min)

Acceleration/Deceleration over 75 m (250 ft) to reduce 'g' forces, or <= 0.085 m/s^2 (0.28 ft/s^2)

Assumptions:

Discharge time:	10.0 min
Load time:	13.0 min
Docking time:	5.0 min

Therefore the trip time is as follows:

Loading container and release:	13.0 min
75 m acceleration to 5.1 m/s :	1.0 min
6100 m at 5.1 m/s:	20.0 min
75 m deceleration:	1.0 min
Discharge time:	1.0 min
Acceleration to 5.1 m/s:	1.0 min
6100 m at 5.1 m/s:	20.0 min
75 m deceleration:	1.0 min
Docking:	5.0 min
TOTAL TIME	63.0 min = 1.05 hr

The concept consists of a 190 m^3 (250 yd^3) capacity container that weighs over approximately 100 Mg in sea water when filled. The container is made of aluminum and is 4.3 m (14 ft) in diameter and 6.6 m (21.5 ft) in height. It is designed to carry materials having a bulk specific gravity up to 1.25. The container is filled with waste material by an auger or conveyor through a flanged interface. The estimated time for loading the container is 13 minutes, using dual 1200 Mg/hr conveyors.

Ship motion in the open sea, especially motion caused by wave action, makes handling the container difficult. The dynamic input results in very high loads when handling such a large mass.

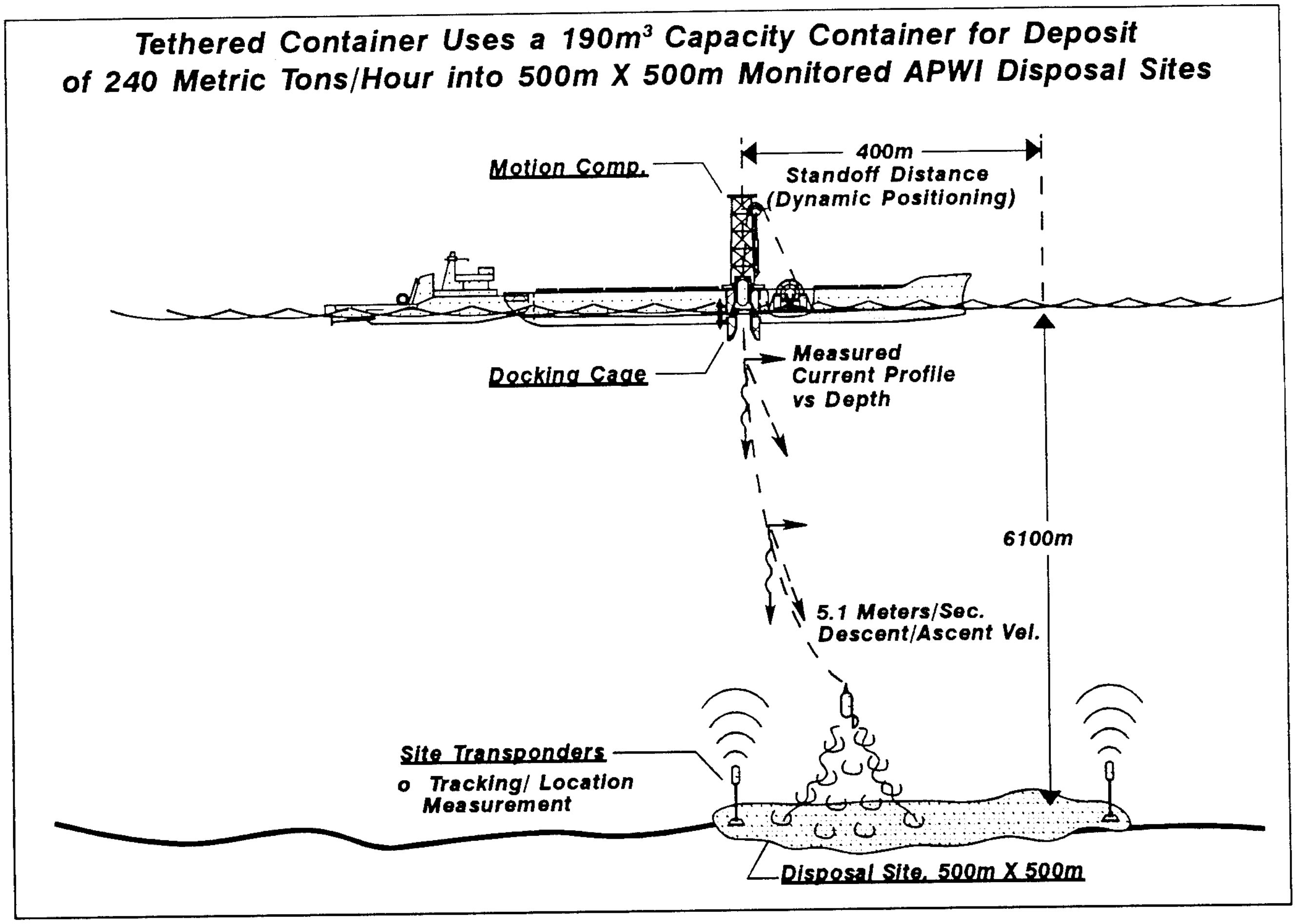


Figure 5.5.1-1
Tethered Container

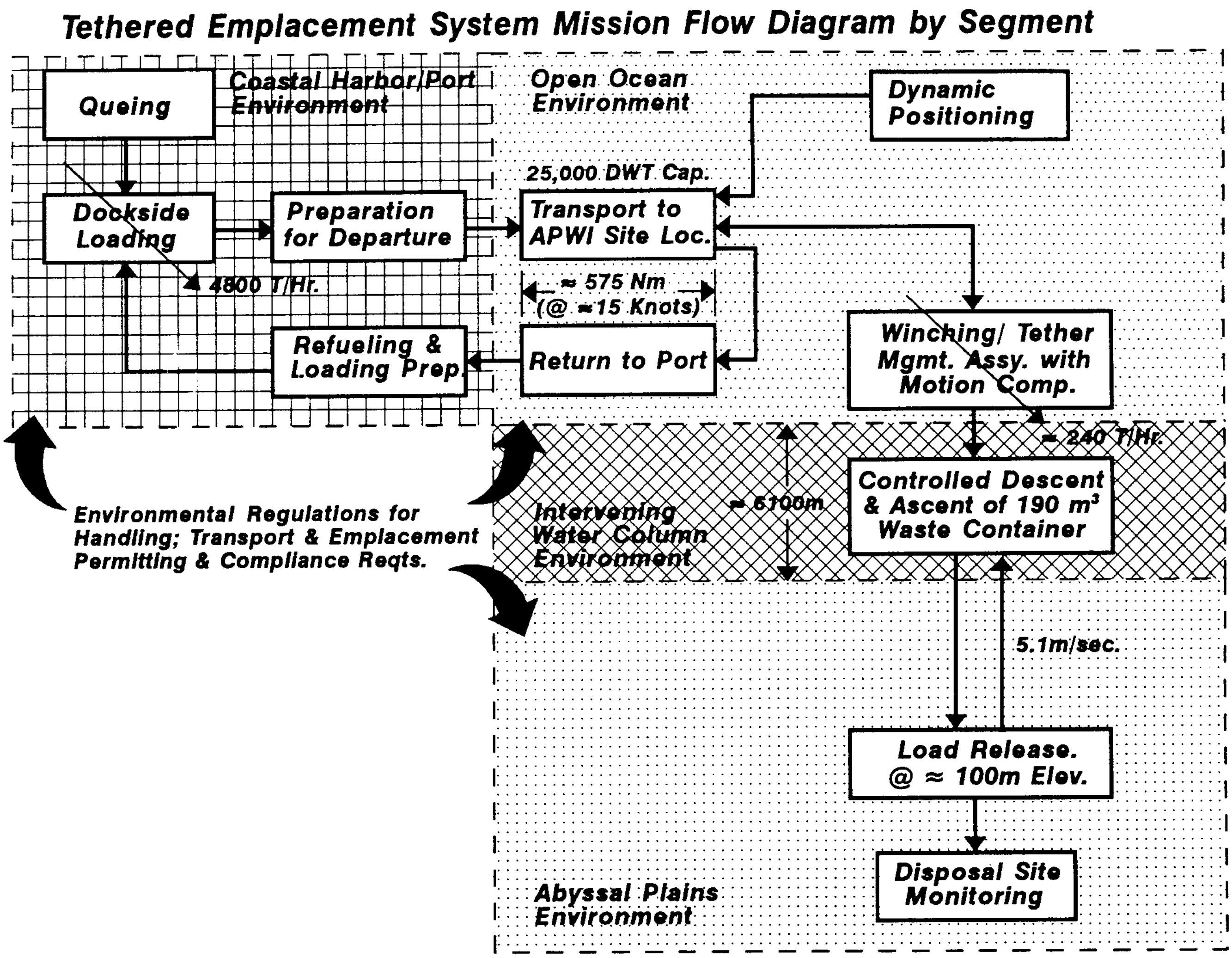


Figure 5.5.1-2
Tethered Container Process Flow Diagram

The handling system is designed to minimize the dynamic inputs, thereby reducing the apparent loads on the tether and container. The handling system consists of a docking cage, a heave compensation system, and a winch which operates through a moonpool in the support vessel.

The most effective means of reducing the effect of ship motion on the handling system and thus the container is to operate the system through a moonpool. The moonpool reduces the effects of wave action during operation except for heave. The moonpool design for this system is critical for several reasons. First of all, the size of the moonpool in the support vessel (approximately 10 m X 10 m) is very large to accommodate the waste container. The vessel will be significantly modified and strengthened to incorporate a moonpool of this size. Secondly, because of the moonpool's large area, the vessel will have deployable skirting around the moonpool's opening that extends down from the bottom of the vessel. This skirting will help dampen wave action inside the moonpool.

The container is captured in a retractable docking cage during the loading, launch, release and retrieval of the waste container. The docking cage travels vertically on a track through the moonpool for filling, release, and recapture of the container below the air/water interface. The docking cage will protect the perimeter of the moonpool from damage due to angular motion of the vessel. The docking cage must react to the side loads imparted on the container as the vessel reacts to the seas. The cage requires a larger moonpool but makes the launch and recovery of the large container safer.

The winching assembly would require approximately 4500 hp at 85% efficiency. The winch drum barrel size would be approximately 5.1 m (16.7 ft) in diameter to provide a d/D (diameter of tether/diameter of winch drum barrel) of 40:1 to minimize tether induced stresses due to bending. Assuming an 8 wrap configuration, the flange-to-flange spacing would be approximately 6.1 m (20.0 ft). A levelwind assembly would be required to maintain uniformity in the tether layup onto the winch drum.

The heave compensation system prevents the rope from being impacted by abrupt vertical acceleration (snap loading). A hydraulically tensioned head sheave located above the moonpool dampens heave. The hydraulic cylinders maintain a preset pressure. When the ship heaves upwards, the increased pressure is relieved and the sheave maintains position. Conversely, as the ship heaves downwards the pressure to the cylinders is increased to the preset pressure. The heave compensation system will mitigate the otherwise expected heave accelerations which could be as great as 1.3 g (17.7 m/s^2 or 58 ft/s^2) in sea state 5.

Based upon a maximum allowable acceleration of 0.085 m/s^2 (0.28 ft/s^2) due to changes in tether deployment or retrieval speed, the minimum induced change to the tether line tension would be approximately +/-43 kN (9,400 lb). Accounting for the added mass of "entrained water," which is approximately equal to that of the container displacement volume, and including the mass of the tether at 78 metric tons (Mg), yields a line tension change of +/-84 kN (18,400 lb). The magnitude of the change in tether line tension is directly proportional to the acceleration level. Noting that the heave compensation system must be capable of mitigating expected heave acceleration levels as great as 1.3 g (17.7 m/s^2 or 58 ft/s^2) in sea state five, we see that sea state effects generate approximately 200 times the acceleration levels of that of normal winching operation. The heave compensation system must therefore have capability to isolate approximately 99.5% of the induced heave acceleration levels from that of the tether management system, if "constant tension" values are to be maintained at +/-10% of the desired setpoint. This value of +/-10% is at the upper limit of achievable tension control capability for heave compensation systems. In the event of failure of this system, or in situations or degraded operational performance, the tension fluctuations could be expected to rapidly exceed that of the tether breaking strength.

The tether selected for the concept is a synthetic line. Synthetic line is more easily handled than the alternatives and offers a great benefit of a low in-water weight. Synthetic line has a good strength to weight ratio as compared to other options and is resistant to environmental degradation. The synthetic line chosen is an aramid-fibered line.

This aramid-fibered line has a 8.1 kN (1.8 million lb) break strength in a virgin, unspliced condition. The line is 0.127 m (5 in) in diameter and requires the use of 5.1 m (16.7 ft) minimum diameter sheaves. The 0.127 m diameter line has a block creel of 300 m (1000 ft), which is the maximum strand length that can be wound on a single rope making machine's bobbin. Therefore, a continuous 6700 m (22,000 ft) section of the 0.127 m diameter, 7x19 line will have no less than 22 splices per strand times 7 strands. The line will be derated at least by 10% for the splices. The recommended working load of the line should include at least a factor of safety of 7 for heavy use. Again derating the line for extended fatigue life, the recommended working load of the line is 1.02 kN (230,000 lb).

Aramid-fibered line demonstrates elastic properties similar to wire rope. The line will not tolerate any impact or shock loads. If the line is stopped abruptly or if it is otherwise shock loaded, it will part. This sensitivity to impact loading drives the handling system design.

The tether line of the Tethered concept is very likely to fail by premature fatigue because of the natural frequency of the line. The natural frequency of the tether is in the same range as expected ship motion inputs. The cross current vortex shedding also produces frequencies in the same range. Both of these conditions can excite the rope and lead to strumming or other large oscillations in the rope. The excited rope will fail due to fatigue if these conditions are present.

Finally, the primary downfall of the tethered concept is its low waste emplacement rate caused by manufacturing and handling limitations on existing diameters of synthetic line. There are many other limiting factors; however, the tether represents the driving force which negatively impacts the concept. The tether characteristics drive the entire concept design and limit the system capacity. The maximized system yields 250 metric tons (Mg) of waste material emplaced every 1.05 hr or 240 Mg/hr at abyssal depths. This capacity falls very short of the economic minimum baseline of 4800 Mg/hr emplaced. As a result, the Tethered Container does not qualify as a viable concept of APWI. Therefore, this concept is terminated at this point from any further consideration.

5.6 COMMON ELEMENTS

Common elements are defined as those issues that are present and basically identical regardless of the APWI concept. Common elements include transporter system, handling systems, waste stream containers, docking space, interface of APWI concept with waste streams, and isolation site waste capacity.

5.6.1 TRANSPORTER SYSTEM

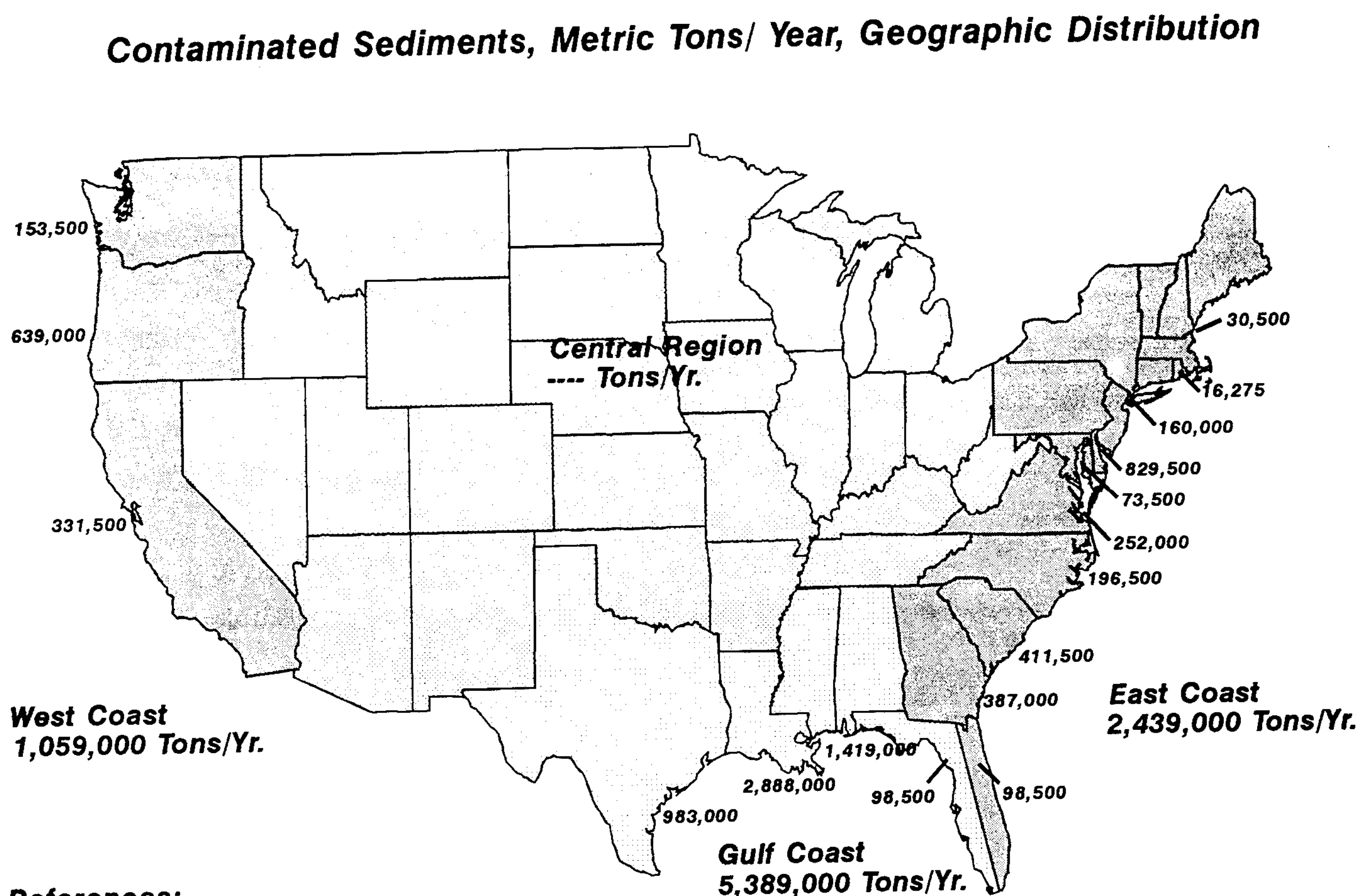
The average volumes of APWI waste stream generation in coastal states is shown in Figures 5.6.1-1, 5.6.1-2, and 5.6.1-3 for contaminated dredged material, sewage sludge, and municipal incinerator fly ash, respectively. The totals for each coast were divided by the number of major ports for that coast (Section 5.6.4). The three coasts were then averaged together. The system level requirement is 2.5 million wet metric tons per port per year. The dredged material volumes listed in the maps are in situ at around 70% solid; the volumes were converted to 20% solids reflecting hydraulic dredging equipment operating at low speeds for contaminated dredging operations. The waste stream volumes in the maps are listed in dry tons for sewage sludge and municipal incinerator fly ash; these volumes were converted to 20% solids for sewage sludge and 85% solids for quenched fly ash.

The coastal averages are:

Atlantic	1,500,000 metric tons/year/port
Gulf of Mexico	4,600,000 metric tons/year/port
Pacific	796,736 metric tons/year/port
Average U.S.	2,300,000 metric tons/year/port

The average U.S. coastal generation is rounded to 2.5 million metric tons/year/port. The East Coast average may be skewed lower because of the overlapping of areas surrounding the port facilities. A closer look at the New York vicinity waste stream generation gives a better idea of the magnitude of waste that may be expected at this port. The New York Harbor vicinity's waste stream generation is broken down in Table 5.6.1-2.

The total volume of waste stream applicable to isolation by APWI in the New York Harbor vicinity is 3.13 million metric tons. Although this appears higher than the East Coast average, this is still a very conservative number using 5% as the percentage of dredged material contaminated to the point requiring special handling and management. In some New England ports, the percentage of contaminated dredged materials may be as high as 50% (Hoskins and Silva 1994).



References:

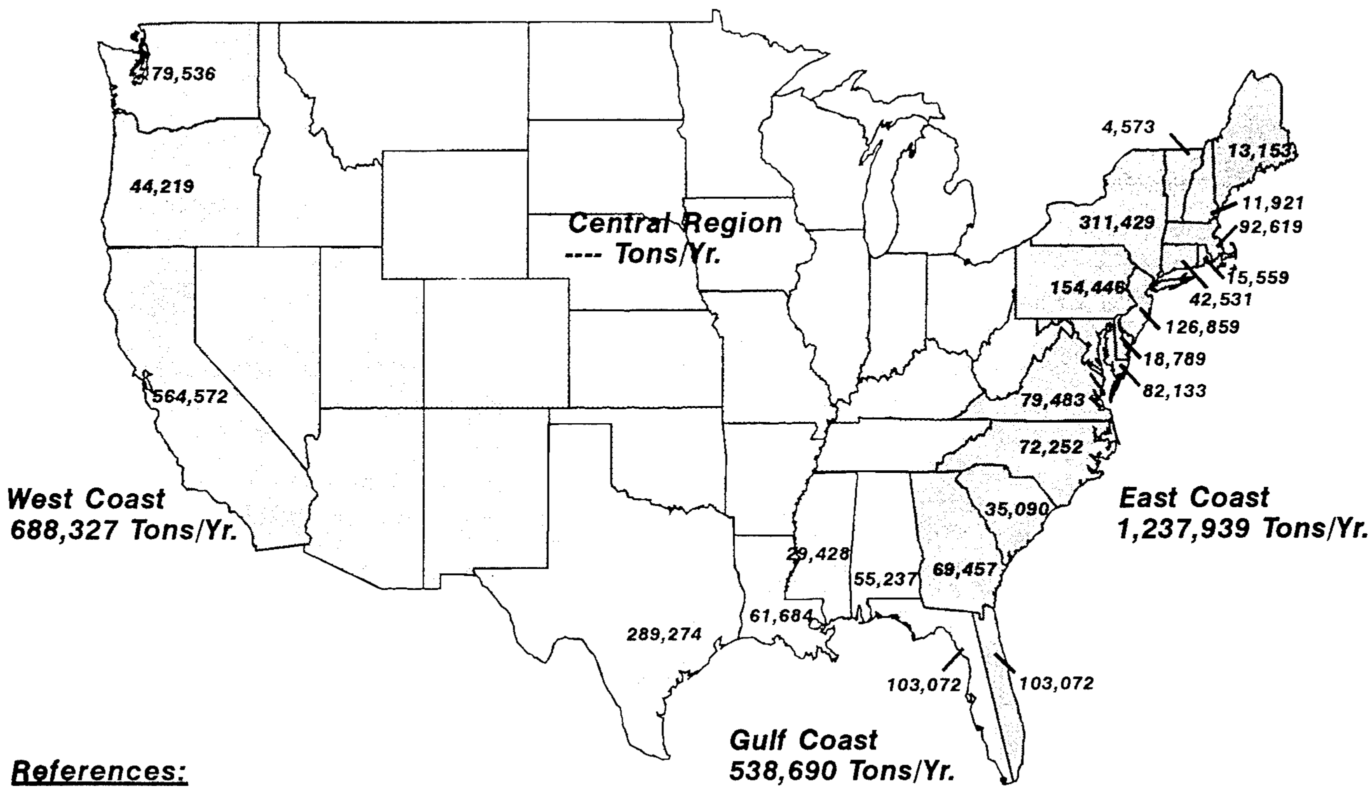
Demars/ Chaney, Geotechnical Engineering of Ocean Waste Disposal, 1990, American Society for Testing and Materials, Philadelphia.

* Adjusted Total Reflecting Contaminated Sediments as ≈ 5% of Total

** Excludes Some Corp of Engineer Districts, and Commercial Dredging Operations

Figure 5.6.1-1
Coastal Distribution of Contaminated Dredged Material

Sewage Sludge, Metric Tons/ Year, Geographic Distribution



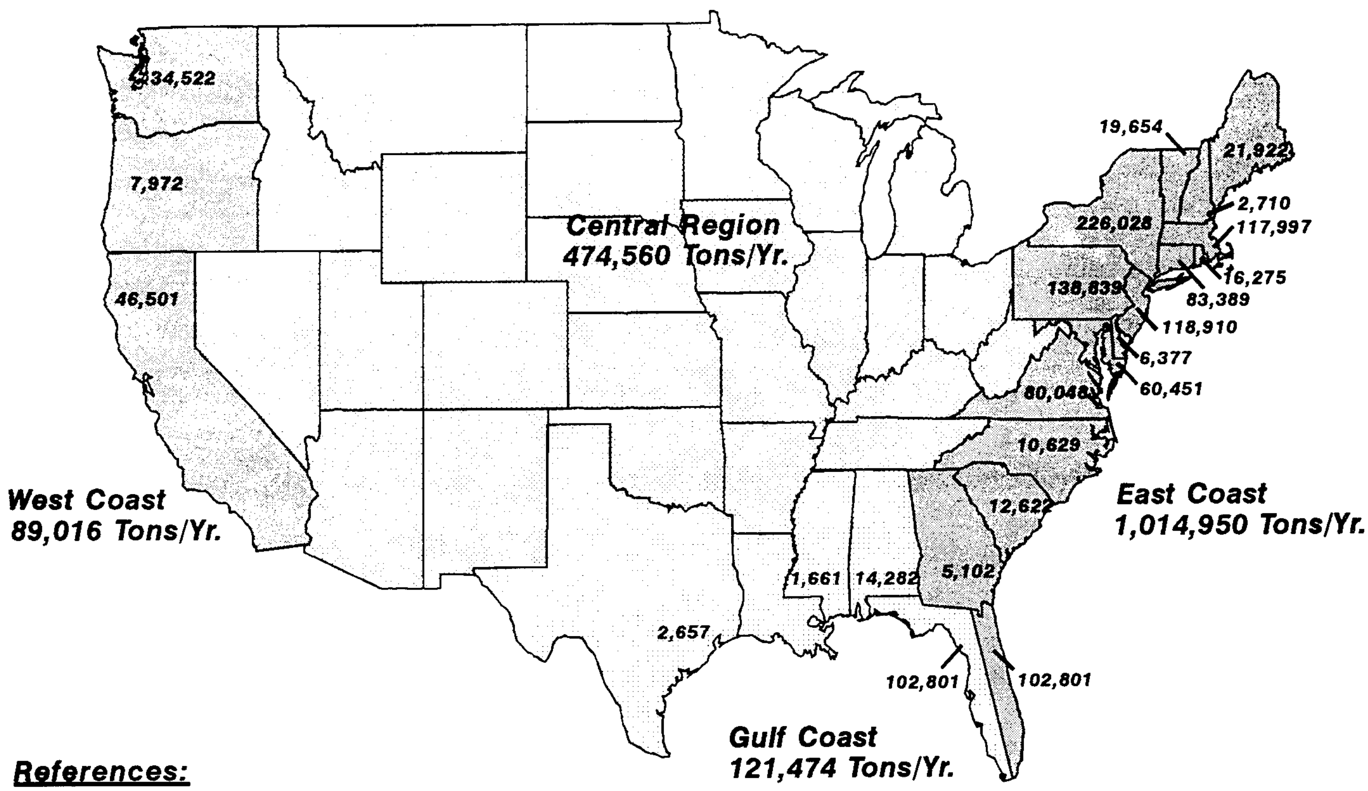
References:

Total Coastal Sewage Sludge = 2,464,956, vs Total of 4,453,967 Metric Tons

** Based Upon 47Lbs./ Person / Year--1979 Population Survey*

Figure 5.6.1-2
Coastal Distribution of Sewage Sludge

Fly Ash, Metric Tons/ Year, Geographic Distribution



References:

Bereny; Eileen and Robert N. Gowd. 1993-94 Resource Recovery Yearbook Directory and Guide. Governmental Advisory Associates, Inc., New York

Governmental Advisory Associates, 1993. U. S. Waste Incinerators (No Energy Recovery). Governmental Advisory Associates, Inc., New York

Figure 5.6.1-3
Coastal Distribution of Municipal Incinerator Fly Ash

WASTE STREAM	TOTAL VOLUME OF WASTE GENERATED (MILLIONS OF METRIC TONS)	TOTAL VOLUME OF WASTE APPLICABLE TO APWI (MILLIONS OF METRIC TONS)
DREDGED MATERIAL	6(1)	.3(4)
SEWAGE SLUDGE	.48 (DRY METRIC TONS)(2) 2.4 (WET METRIC TONS AT 20% SOLID(3)	2.4(2)
INCINERATOR FLY ASH	.43(5)	.43(5)

(1) US Army Corps of Engineers Dredging Statistics Program, 1992.
(2) Based on 47lbs/person at 20% (EPA, 1992).
(3) DeSpain, 1994 (Attachment 7).
(4) Zarba, 1989
(5) Berenyi and Gould, 1993

Table 5.6.1-2
Annual Volumes of Waste Streams Generated in the New York Harbor Vicinity

Figure 5.6.1-4 shows an APWI transporter performance evaluation versus different transiting distances. The annual volumes of waste in millior: metric tons per year is shown for bulk transporters of different sizes for one way distances ranging from 250 to 1000 nmi. Values are highlighted for the East Coast, Gulf of Mexico, and West Coast average transiting distances. The assumed loading and unloading rate for the calculation of this graph is 4800 metric tons per hour. As can be seen in this figure, a bulk carrier of 25,000 DWT would be sufficient for the average waste volumes. The major ports used to calculate average distances are listed in Section 5.6.3.

The 25,000 DWT transporter gives the closest capability for the national average of 2.5 million metric tons/port/year. Specifically, the 25,000 DWT transporters are capable of emplacing 3.62 million metric tons per year from the Gulf of Mexico ports to the Gulf APWI site; 2.68 million metric tons from the Pacific Coastal ports to the Pacific APWI site; and 2.2 million metric tons from the Atlantic Coastal ports to the Atlantic APWI site.

Figure 5.6.1-5 shows an APWI concept evaluation in millions of metric tons emplaced when fed by a 25,000 DWT transporter for the coastal ports identified in Section 5.6.3. This figure shows the annual volumes that can be emplaced when factoring in the concept capabilities as well as the transporter capacity. The annual volumes remain unchanged from Figure 5.6.1-4 when examining the Surface Emplacement, ROV Glider, and Direct Descent Disk concepts, but decline slightly when examining the Pipe Riser concept because of the decreased unloading rate caused by the need for additional slurryizing of the waste. Therefore, the 25,000 DWT transporter, factoring in the four concepts' unloading rates, is still capable of handling the national averages with one per port.

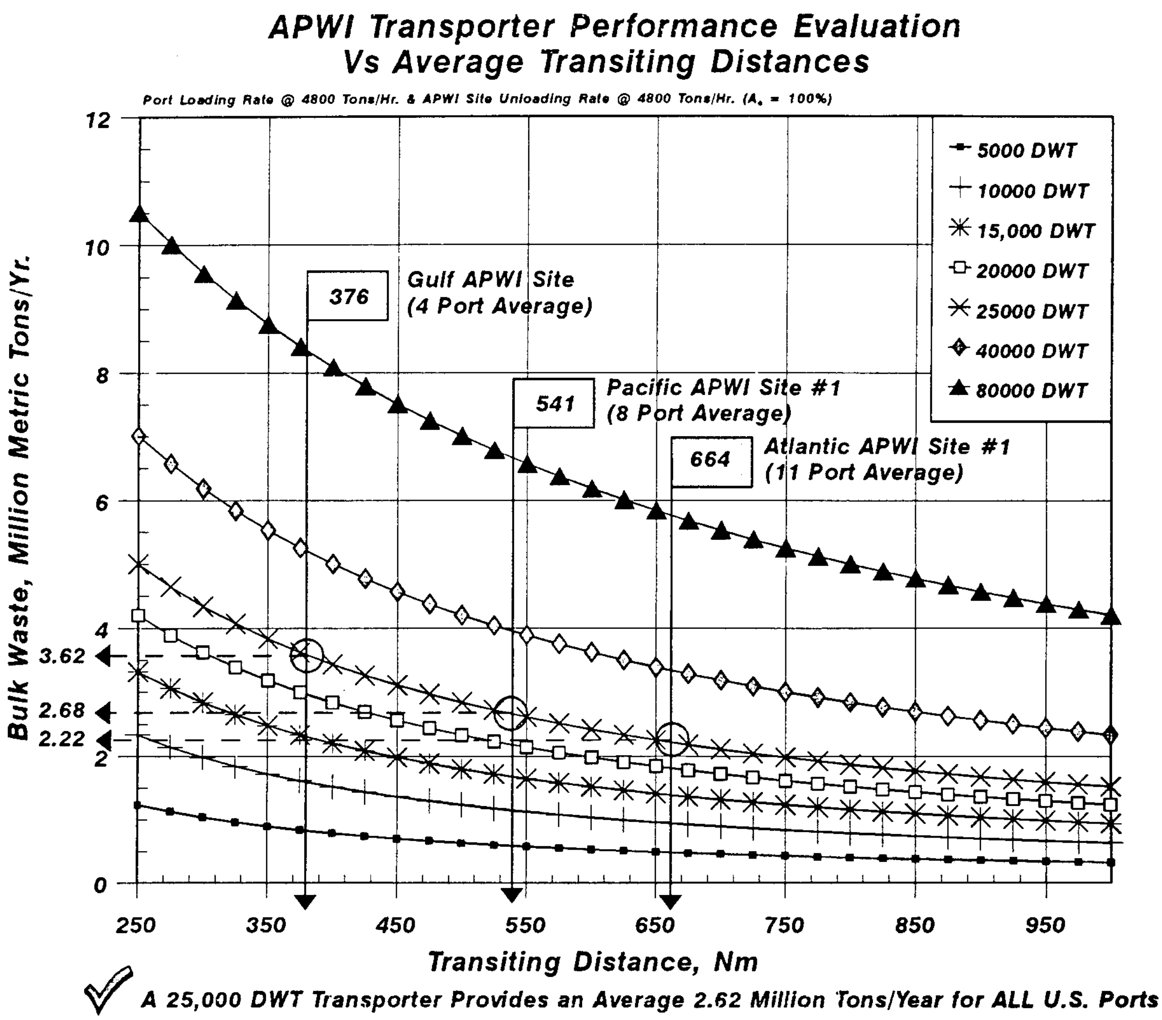


Figure 5.6.1-4
APWI Transporter Performance Evaluation

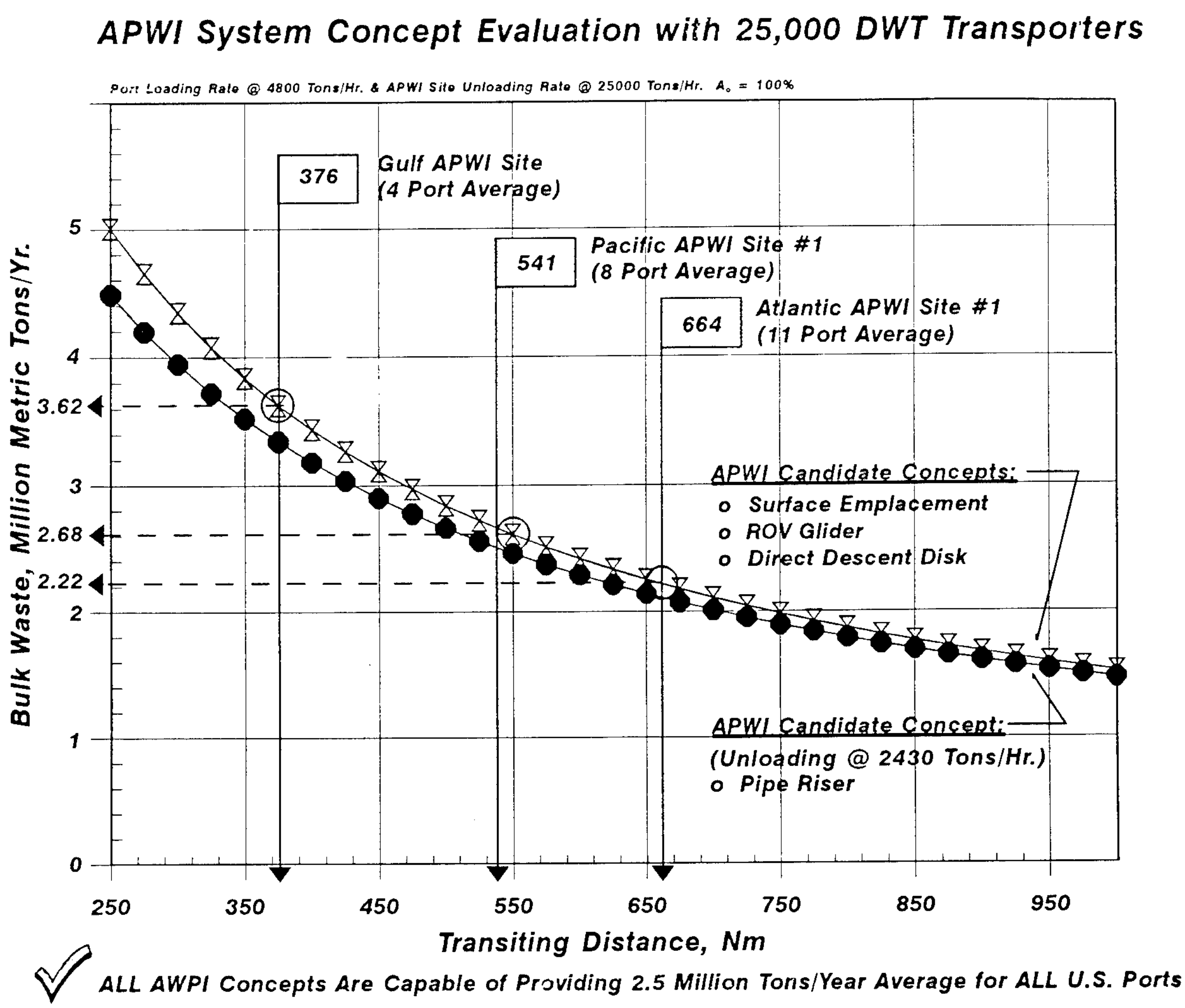


Figure 5.6.1-5
APWI Candidate System Concept Evaluation

To further examine the optimal size of transporter, including the issue of multiple smaller transporters instead of the single transporter, transporter sizes with various loading rates were plotted against the capital cost per ton of waste emplaced (based on the capital cost of the transporter per ton of waste emplaced). Figure 5.6.1-6 examines the relative capital costs per ton for different transporter sizes loaded at different rates. The loading rate had a major impact on the cost per ton of waste emplaced; this impact increases as the transporter size increases. It is apparent that 4800 tons/hr is the preferred loading rate. Also, with existing equipment, it is the highest realistically achievable rate available. Examining the lower curve, the cost per ton continues to decrease indefinitely as transporter size increases. This would imply that the larger the transporter, the cheaper per ton the emplacement costs would be. Upon further examination of the curve itself, from zero to 25,000 DWT, the price per ton drops sharply with every increase in transporter size. From 25,000 DWT to 145,000 DWT, although the price is still decreasing, the curve is starting to level off, so the tradeoff of increasing the transporter size does not impact the savings per ton of material emplaced as much.

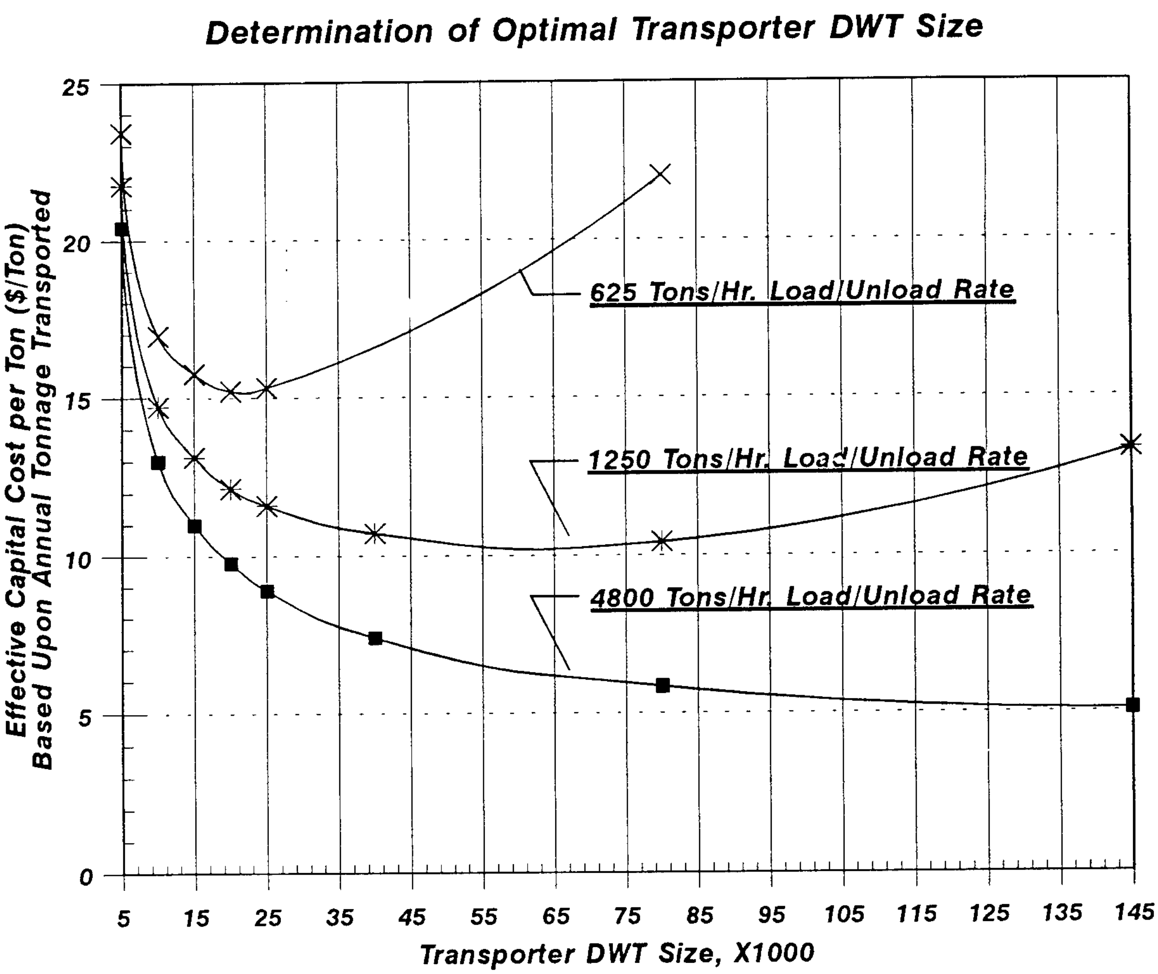


Figure 5.6.1-6
Determination of Optimal Transporter DWT Size

This trend is similar to the law of diminishing returns. For example, the capital cost per ton emplaced for a 25,000 DWT transporter is approximately $9.00/ton; for a 40,000 DWT transporter it is $7.00/ton. With a savings of only $2.00/ton, the 40,000 DWT transporter is almost double the size of a 25,000 DWT. There are disadvantages associated with a larger sized transporter including restrictions on docking space and increased draft. Inversely, a 20,000 DWT transporter's capital cost per ton of material emplaced is approximately $9.50 per ton. The 25,000 DWT transporter provides an additional 25% of Dead Weight Tonnage at a cost increase of only $0.50 per ton. The capital costs in Figure 5.6.1-6 were derived from Figure 5.6.1-7. This graph shows the comparison of an APWI special purpose 25,000 DWT Integrated Tug Barge to existing 25,000 DWT transporters including bulk carriers, single, and double hulled tankers. The existing bulk carrier and tankers' prices were found in Maritime Log 53rd Annual Yearbook and Marine Review, June, 1994. The APWI special purpose 25,000 DWT transporter was priced in an evaluation by John J. McMullen and Associates (Hightower et al. 1994, Attachment 1 "Surface Emplacement Vessel Tradeoff Issues".

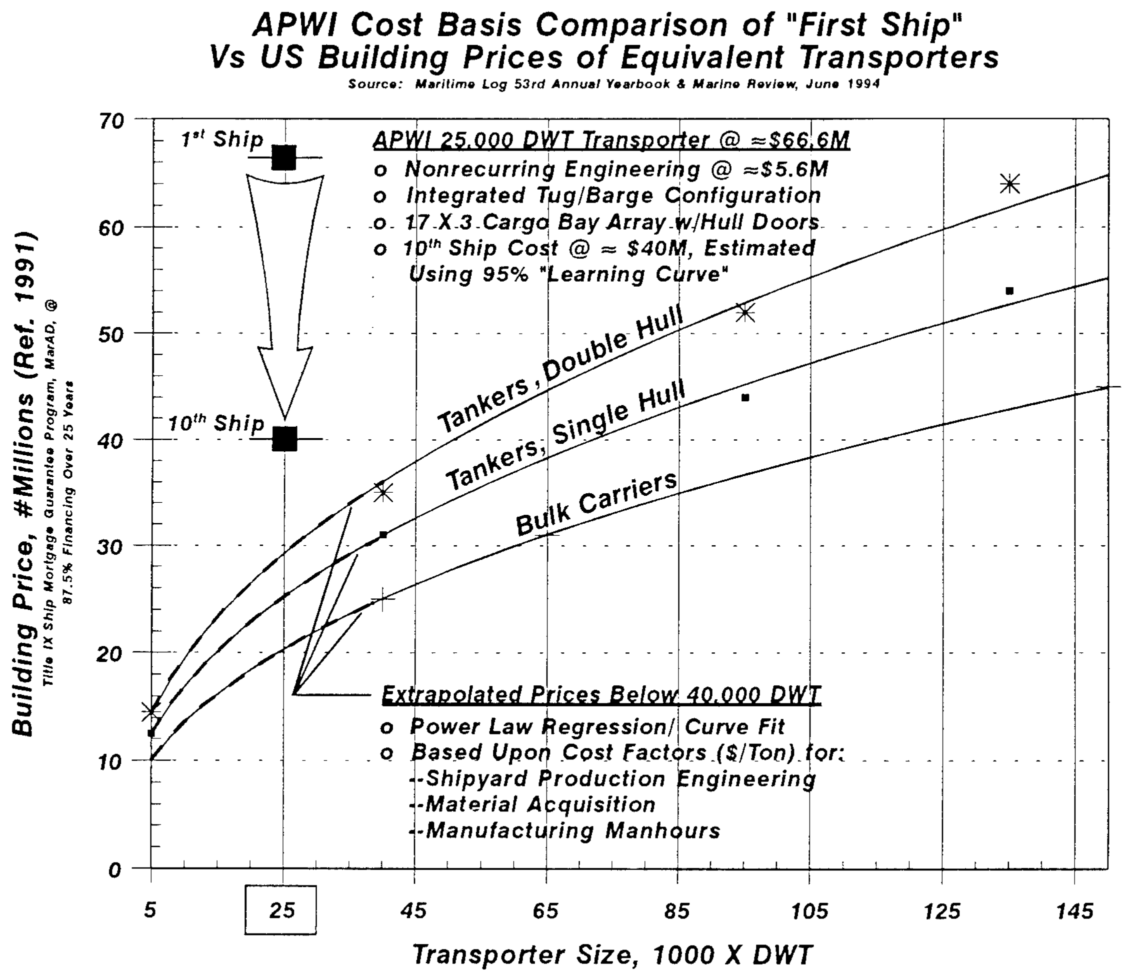


Figure 5.6.1-7
APWI Cost Basis Comparison Building Prices of Equivalent Transporters

To select the appropriate transporter type, an Integrated Tug/Barge was compared in operation and costs to a self-propelled bulk carrier (see Hightower et al. 1994, Attachments 1 and 3).

Surface Emplacement would utilize an ITB vessel similar to that described in Hightower et al. (1994), Attachment 1, with the alternative being a more conventional self-propelled bulk transporter of approximately 39,000 metric ton displacement, 25,000 DWT.

The ROV Glider would also use a purpose-built Integrated Tug/Barge (ITB) configuration. The barge configuration (similar to a catamaran) would provide twin hulls, each approximately 3.7 m (12 ft) X 222 m (728 ft), with an open space-frame deck structure spanning between the hulls.

The Direct Descent Disk would also require a purpose-built ITB vessel configuration possessing unique features to facilitate the transport, release, and recovery of up to five 36.6 m (120 ft) diameter Disks. However, this concept uses self-powered "barge segments" or Disk Floater Modules connected together using Flexor or Sea-Link couplings similar to that required to effect an integrated tow between a barge/scow and the tug. The individually-powered Floater Modules would be utilized to gather-up the five Disks, and return to the host tug for re-linking and return to port. Normally, decoupling of an integrated tow in the open ocean would not be recommended, however, the Disks possess a very high degree of righting moment/metacentric height, and would be exceptionally stable in sea state 5 conditions, facilitating both the docking and the locking engagement of the individual modules. Of special interest, is the potential for a very large (50%) saving in transport vessel structural weight, and in related shipyard fabrication cost savings, resulting from both fabrication (outfitting only) assembly ease and volume production of standardized elements. For the ITB configuration consisting of five Floater Modules, beam dimension would be 40.3 m (132 ft), length (overall) 275 m (900 ft), and draft 4.9 m (16 ft).

The Pipe Riser concept would utilize vessels similar to those selected for Surface Emplacement concept, but without the added complexity of hull doors.

5.6.2 HANDLING SYSTEMS

Contaminated dredged material will be loaded into the APWI vessel at the dredging site. Sewage sludge and municipal incinerator fly ash will be transported by land to the port and loaded onto the APWI vessel from a dockside holding facility. Determination of the appropriate handling system is primarily predicated upon interface requirements with the waste stream products physical state (e.g., percent solids, bulk specific gravity, amenability to hydraulic or mechanical transfer). Each waste stream possesses unique physical properties, which may be highly variable depending on the waste point of origin. Based on interviews with experts, facility tours, and reference materials, assumptions have been made regarding the physical state of the wastes upon arrival at the port. A detailed write-up on these assumptions follows in section 5.6.5.

Contaminated dredging operations using normal hydraulic equipment at low rates to reduce plume generation usually result in dredged materials containing around 20% solids. Hydraulic loading of the 20% solid dredged material is the most feasible handling method because hydraulic lines can be readily positioned to fill the many compartments of the APWI concepts. One hydraulic line can load an APWI vessel at 4800 metric tons per hour which, as shown in Section 5.6.1, is the most economical of the feasible loading rates. It would take four mechanical systems, which load a maximum of 1200 metric tons per hour each, to equal one hydraulic line. Several new special purpose dredges have been developed for dredging contaminated sediments, yielding sediments of 30-50% solids. According to the Civil Engineering Handbook (Merritt 1983), 25% is the upper limit on the pumpability of dredged material; therefore, dredged material of more than 25% solids would be mechanically transferred. If mechanical loading of the APWI vessel at the dredge site is needed, it can be done by the use of mechanical handling systems, such as clamshell buckets. This would be needed if the material was mechanically dredged. Four parallel systems would be required to load at a rate of 4800 metric tons per hour. For this study, it is assumed that most dredged material applicable to APWI will be hydraulically pumpable, and would have a slurry bulk specific gravity of approximately 1.25.

The percentage solid in which the waste streams arrive at port will determine the type of handling system used. Sewage sludge will arrive at port containing approximately 20% solids; fly ash will arrive at port containing between 75 and 85% solids. Mechanical handling systems such as screw conveyors have the capability of handling both sewage sludge and municipal incinerator fly ash in the above mentioned physical states. These mechanical handling systems would be used both to unload these two waste streams upon arrival at port into the holding facility and to transfer the wastes from the holding facility to the APWI vessel, either into containers (Surface Emplacement, Direct Descent Disk, and ROV Glider concepts) or into bulk holds to be taken to the Pipe Riser. It is recommended that sewage sludge and municipal incinerator fly ash be mixed together in a ratio of approximately four parts sewage sludge to one part fly ash, yielding a mix bulk specific gravity of approximately 1.24 (to be discussed in section 5.6.5).

Characteristics of transporter systems envisioned for APWI dictate a unique approach to mechanically filling a large number of cargo bays at port. Moving a mechanical loader to many compartments is a large engineering feat, especially when paired with the desire to transfer materials at 4800 metric tons per hour. Coordinating four mechanical systems to reach every compartment without collision is a difficult task.

For purposes of illustration only, a self-contained port facility with all associated bulk waste storage, mechanical handling, and transfer equipment is depicted in Figures 5.6.2-1 and 5.6.2-2. Although this system is shown for the Direct Descent Disk, the basic idea can be adapted to other concepts. Figure 5.6.2-1 shows a modular approach to the port facility storage and docking arrangement. The rail spur runs down the center of the facility, allowing off-loading to the floating storage tanks. The pilotable APWI Disks pull in behind the tanks and attach. Bridge Cranes load the APWI Disks from the associated storage tank. The modular facility would be adaptable

to many sizes and types of docking spaces. Detail of the bridge crane is shown in Figure 5.6.2-2. The bridge crane assembly is a retractable screw conveyor system (number 1) that is fed by a telescoping feed line attached to the associated storage tank. The nozzle of the assembly (number 2) is positionable in the X and Y direction allowing it to reach all compartments of the APWI vessel. A detailed illustration of the retractable screw conveyor is shown in Figure 5.6.2-3. The linkages operate from 0 to 75°, allowing positioning without having to move the entire structure. The adaptability of the technology in this system makes it applicable in various degrees to each concept.

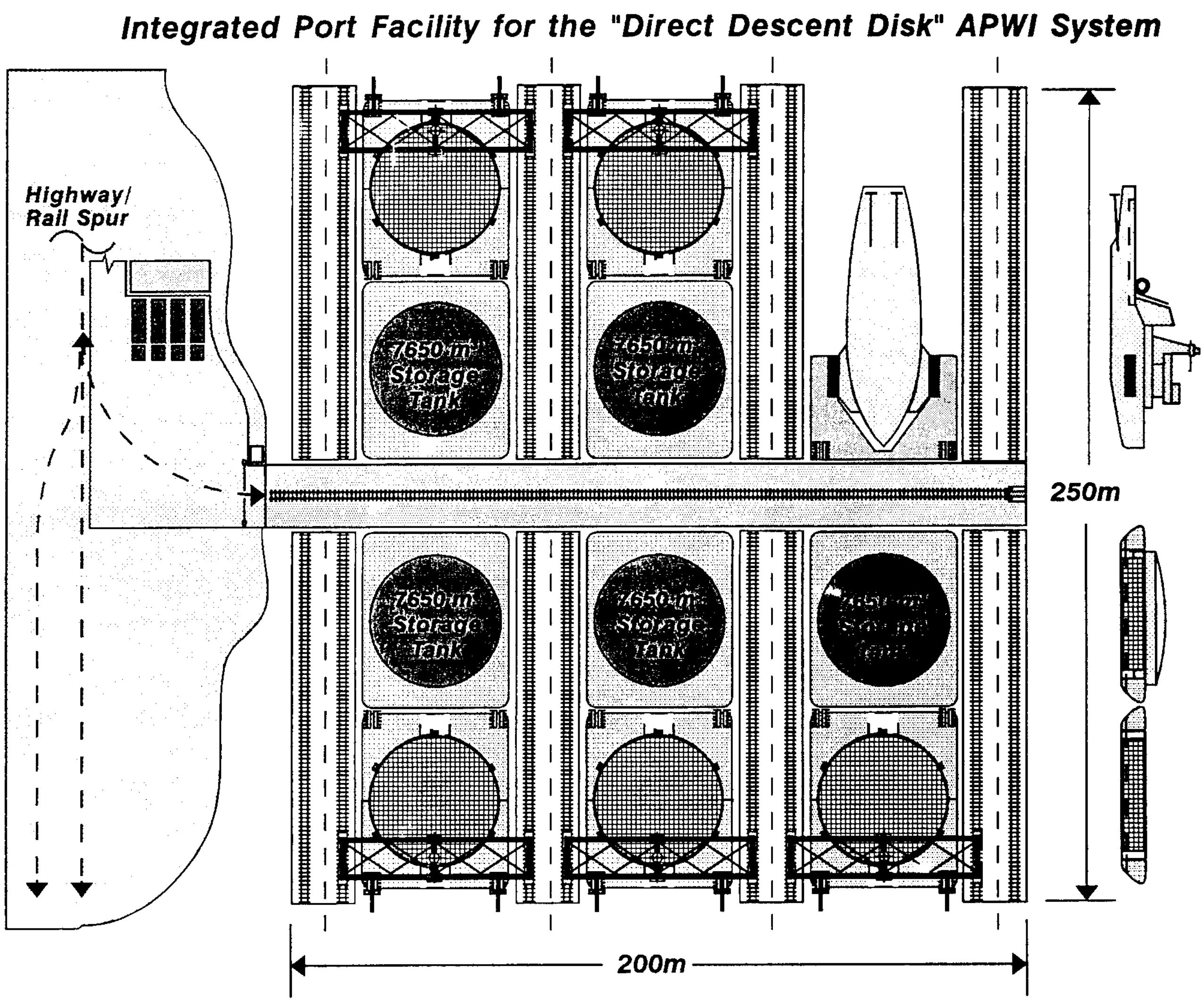
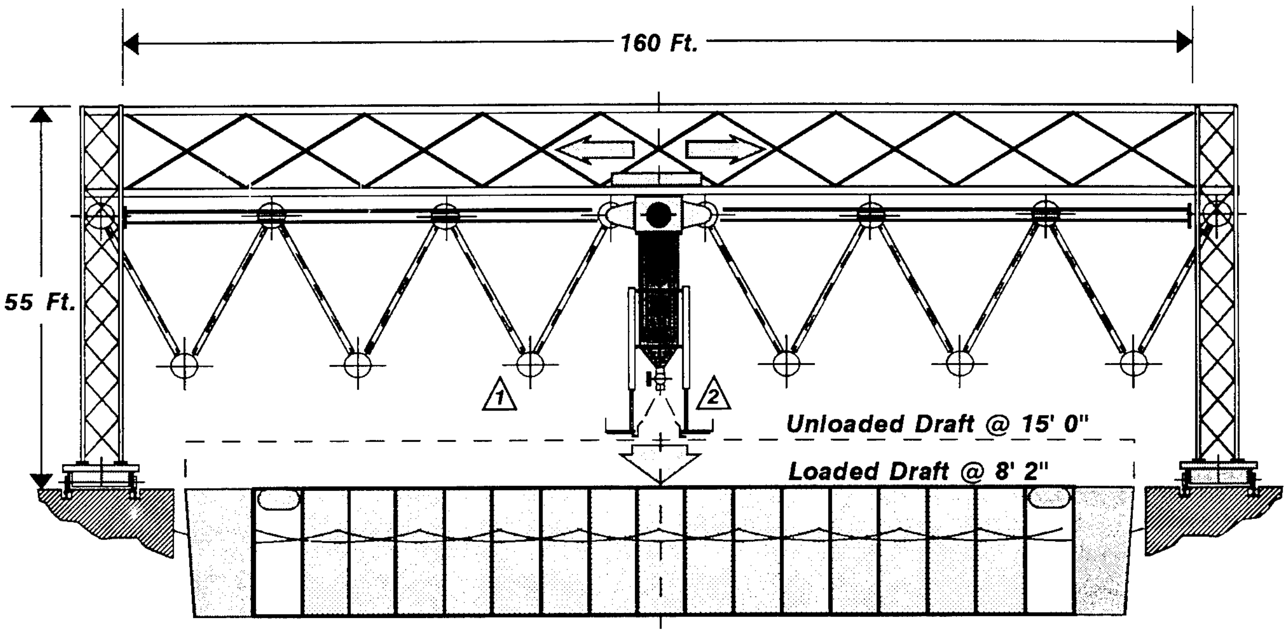


Figure 5.6.2-1
Integrated Port Facility

Port Facility Bridge Crane Assembly for Direct Descent Disks (1 of 5ea.) 75T Live Load Capacity, with X -Y Indexed Hopper for Cell Batch Loading



1. ***Dual Feed, 6-Stage Auger Screw Conveyor System, 1260 T/Hr. Bulk Capacity***
   - *50 HP Hydraulic Drive Motors Provide Powe' for Each 30 Ft. Long Segment*
   - *Flow Area = 1.00 Ft.^{2}; Screw Pitch @ 6.00 in.; Rotational Speed @ 1800 RPM.*
   - *0.125 Thick TFE Lining for All Interior Rotating & Static Surfaces*

2. ***Batch Loading Hopper Assembly, 28.7 Yd.^{3} Capacity, with Telescoping Feed Line***
   - *Operator Platform Positioning Directly Above Each Cell Permits Direct Access for Cargo Cell Bag Insertion, Monitoring of Fill Operation, and Final Closure*
   - *Negative Pressure Enclosure,with Filtered Exhaust, Provides Dust/Odor Control*

Figure 5.6.2-2
Port Facility Bridge Crane Assembly

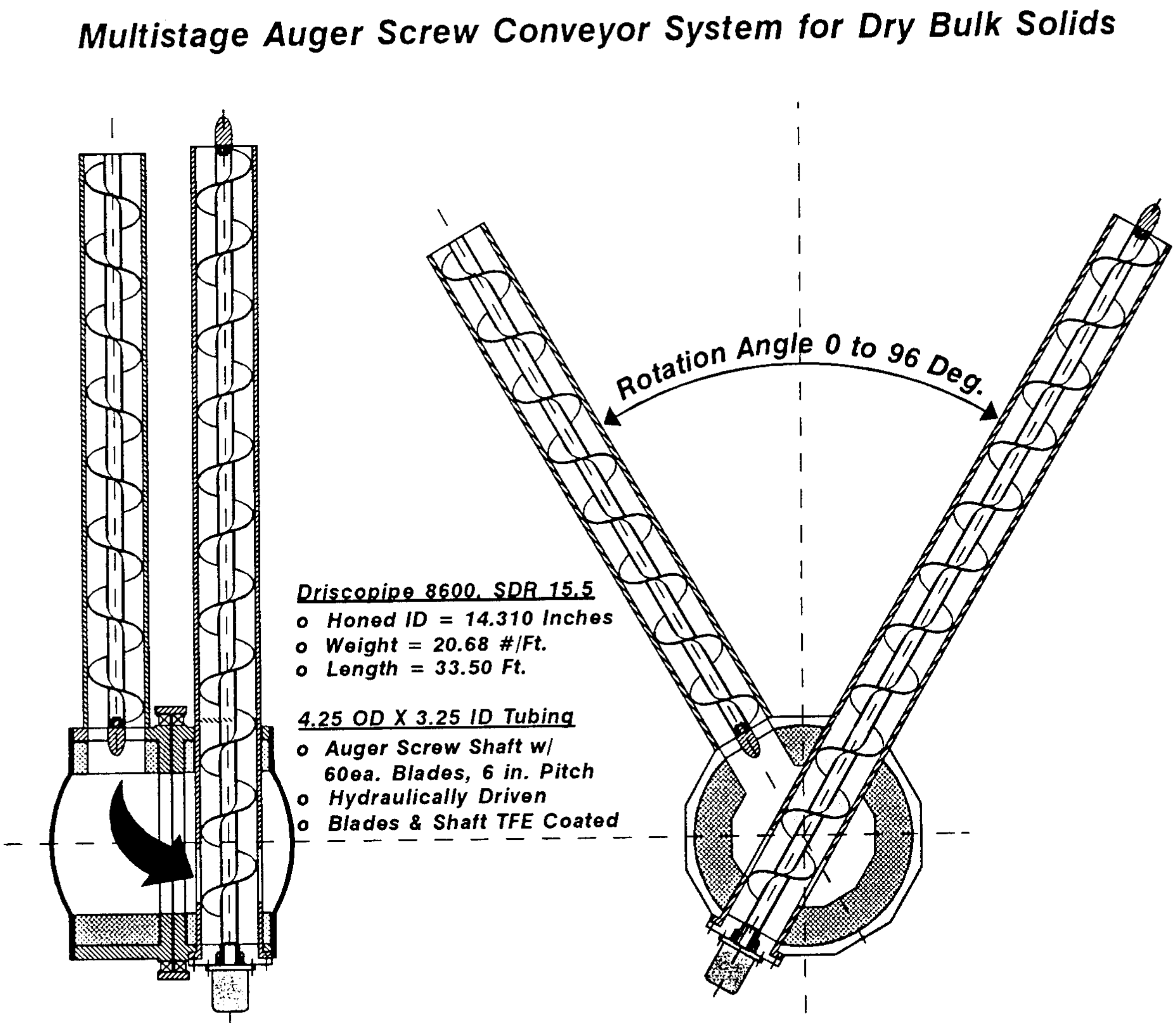


Figure 5.6.2-3
Multistage Auger Screw Conveyor System for Dry Bulk Solids

5.6.3 CONTAINERS

Spill or leak prevention is of paramount importance, including prevention of waste loss in the intervening water column at the APWI site. Consequently, selection of the bag type to be utilized for Surface Emplacement, ROV Glider and the Direct Descent Disk concepts dictates the use of nonporous (for Fly Ash and Sewage Sludge) bag fabric with densities greater then seawater (London Dumping Convention, MPRSA, and MARPOL compliance). Disposable bags deposited at abyssal depths, susceptible to degradation and/or being separated from the emplacement mound, must not be positively buoyant. Otherwise, violation of the London Dumping Convention, MPRSA, and MARPOL would result. The bag materials from Chemfab, with fiberglass substrate and PTFE (Polytetra-fluoroethylene) coating grades P.C.10 and Premium 5 Mil., comply with fabric specific gravity requirements. The geotextile bag material from Nicolon would be changed from its current material to polyester, which is heavier than seawater. The Nicolon Geotextile Container has been utilized by the U.S. Army Corps of Engineers (COE) for emplacement of dredged-material-filled, geosynthetic fabric containers (bags) in waters of up to 90 m depth, releasing the bags through split-hull hopper barge/scow vessels. Note that the present approach/method of release imposes very high tearing loads of the bag fabric. Based upon the cell/trap door configurations for the three bag-using concepts, the bags would endure very low induced stresses for wet loading (e.g., floodable cargo cells) and significantly lower stresses for load release. Landing terminal velocities on the abyssal seafloor would be nearly identical to those previously demonstrated using 383 m^3 (500 yd^3) capacity bags filled to approximately 75% of capacity.

5.6.4 DOCKING SPACE

Available docking space at those port sites identified in the system requirements report (Marcy et al. 1994) were researched using the latest edition of the COE's Port Series. Each volume of the Port Series covers a principal United States coastal port area. Associated overhead maps of the coastal port area show the entrance to the port, navigational information such as obstacles and buoy locations, depths of channels, and average weather/climate and tidal data for the area. The Port Series also lists each individual commercial docking space (not including private marinas) and gives a one-third page write-up including the dock owner, dock user, present uses of dock, how the dock is constructed, complete dimensions, handling facilities/equipment, railway connections, highway connections, water supply, electric power availability, fire protection, and available storage areas. In addition, an overhead photograph of the dock may be included. To accommodate any type of APWI vessel selected, the criteria used for APWI dock selection included a minimum of 8 m (27 ft) depth in the navigation channels on the way to and alongside the dock and a minimum dock length of 270 m (900 ft). The Port Series volumes listed in Table 5.6.4-1 were searched and a complete listing of the docks meeting these criteria was compiled and entered into a database. Appendix D contains the complete printout of this database with field definitions. A total of 225 docks met these criteria with 118 of these on the East Coast, 24 on the Gulf of Mexico, and 83 on the West Coast. The equipment and current uses of these docks varied. Table 5.6.4-1 also includes the number of docks from each docking space meeting these criteria.

PORT LOCATION (PORT SERIES VOLUME)	NUMBER OF DOCKING SPACES
Boston, MA	6
New York Harbor including NY and NJ	38
Ports along the Delaware River including Philadelphia	14
Baltimore, MD	23
Wilmington and Morehead City, NC	7
Charleston, SC	5
Savannah, GA	5
Jacksonville, FL	12
Miami, FL	8
Tampa, FL	5
Panama City, FL	3
Pascagoula, MS	2
Gulfport, MS	2
Galveston, TX	8
Freeport / Brownsville, TX	4
San Diego, CA	5
Los Angeles / Longbeach, CA	37
Port Hueneme, CA	3
San Francisco, CA	8
Portland, OR	16
Bellingham, WA	1
Seattle, WA	10
Ports of Alaska	3
TOTAL	225

Table 5.6.4-1
APWI Docking Spaces

5.6.5 INTERFACE OF APWI CONCEPTS WITH WASTE STREAMS

5.6.5.1 GENERAL DESCRIPTION OF WASTE STREAMS

To allow the APWI concepts to interface with the waste streams at port, it became necessary to further define waste as it leaves the treatment facility (sewage sludge), the incinerator (fly ash), or the dredge/hopper (dredged material). Determination of the interface point for each of the waste stream products was made using flow diagrams provided in Appendix E. For each waste stream, the diagrams begin at the point of origin of the waste streams and step through the decisions involved ending in the isolation options. Also included in the diagrams are percentage solids and existing methods to transport the wastes. Additionally, these charts may be used during the cost phase to establish the most cost-effective point of pretreatment and to compare the costs of existing disposal methods.

Dredged Material:

The ultimate isolation method of contaminated dredged material depends partially upon both the dredge type and disposal options available. There are three major types of dredges:

- Suction (dustpan, hopper, hydraulic pipeline, sidecaster) dredges are usually for maintenance projects and are not recommended for contaminated sediments. The dredged material from this method contains from 10-20% solids.
- Mechanical (clamshell, dipper, or ladder) dredges are used for both maintenance projects and new work. Modified versions of these dredges are used for contaminated sediments. Percent solids vary by situation but are usually in the range of 30-50%.
- Combination (cutterhead) dredges are the most commonly used and versatile dredges, incorporating both a mechanical cutter apparatus and suction. Cutterhead dredges can dig and pump all types of materials as well as compacted deposits. The dredged material from this method contains from 10-20% solids.

For standard dredging operations, materials from suction and combination dredges may be pumped into a bystanding hopper or directly into the water. To transfer the sediment from the dredging equipment to the emplacement concept, materials dredged mechanically are loaded into a hopper by the dredge's mechanical apparatus. Materials less than 25% solids may be pumped; materials over 25% are unloaded by mechanical methods (Merritt 1983).

Dredged material to be considered for abyssal seafloor isolation is expected to be limited to that material sufficiently contaminated to warrant special handling, presently about 5% of all dredged material. In contaminated dredging operations, material is usually dredged using special or modified hydraulic/mechanical equipment to limit the uptake of water during the dredging operation. Materials from contaminated dredging operations contain approximately 20% solids by volume.

When estimating the size of a dredging project it is standard practice to use the in situ volume of the sediments as the basis for calculation. This allows the size of the project to be calculated simply by multiplying the length, width, and the depth of sediments to be removed from the dredging site. The in situ volume consists of the sediment solids plus the water contained within the pore space between

sediment particles. In situ sediments contain approximately 70% solids and approximately 30% pore water. Hydraulic dredging brings additional water up with the dredged material. To help estimate the final amount of diluted dredged material for disposal, a bulking factor is added to the in situ volume. The bulking factor is a volume ratio of material placed in a disposal area to material in situ. Bulking factors are site specific because the factor is impacted by many variables (e.g., sediment type, void ratio (defined in section 5.6.5.3), and dredging equipment type). Because of the uncertainty of some of the factors comprising the bulking or "sizing" factor, some disposal areas have been undersized by as much as 50% or oversized as much as 100% for fine grained soils (DiGeorge, Herbich and Dunlap 1980). Presently, bulking factor is mainly used when calculating the anticipated volumes for confined disposal. Even though APWI sites are not confined, because there is a set amount of dredged material that can be transferred to an APWI site per trip, these bulked-up volumes are needed. The dredged material process flow is shown in Appendix E.

Sewage Sludge:

Most municipalities, at a minimum, mechanically dewater their sludge (Hightower et al. 1994, Attachment 7). This produces a sludge of 6-35% solids. Mechanical dewatering equipment includes centrifuges, vacuum filters, pressure filters, and belt filters. The average mechanically dewatered sludge contains about 20% solids and exists in clumps. Mechanically dewatered sludge can be transported by screw or belt-type conveyors. To further dewater sludge, thermal methods of dewatering must be applied. Thermal dewatering adds heat to volatize water in the sludge by either convection or conduction. The upper end of dewatering sewage sludge is only limited by the energy expended (Appendix E). Thermally dewatered sludge usually exists in either cake form with percent solids at approximately 50% or in pelletized form with percent solids of greater than 90%. Thermally dewatered sludge can be transported by screw and belt conveyors and pneumatic pumps. Belts and pneumatic pumps are used to transport dewatered sewage sludge a short distance. For longer distances, pipelines, covered dump trucks, or railroad cars are used. Currently, sludge is transported to licensed landfills for disposal. Most sewage sludge handled by the APWI concepts will be mechanically dewatered to 20%. This process is shown in Appendix E.

Municipal Incinerator Fly Ash:

Most incinerators mix their fly ash with the bottom ash before transporting. Hot ash falls from the grate into the quencher to reduce fire hazard. Ash residue is removed from the quencher either by a drag conveyor (75% solids) or by a method which pushes ash through a chute and hydraulically squeezes it into an ash bunker or discharge hopper (80-85% solids). Ash is loaded into trucks for disposal by one of two methods: either the ash falls directly into a covered dump truck parked beneath the hopper, or a crane places the entire hopper on an 18 wheel truck. Ash is either taken to a general or ash-only landfill. The RESCO Waste-To-Energy Incinerator in Baltimore trucks their ash to a local general landfill. This process is shown in Appendix E.

5.6.5.2 PARTICLE SPECIFIC GRAVITY

The particle specific gravity was calculated for each of the three waste streams to determine particle heaviness compared with seawater. Since essentially no entrapped water exists in either dredged material or fly ash particles, their particle specific gravities are the same as their dry particle densities. Dredged material particle specific gravity is 2.65 and fly ash is 2.5. If each of these specific gravities are divided by the specific gravity of seawater, which is 1.03, it is found that a typical dredged material particle is 2.57 times heavier than seawater, and a fly ash particle is 2.43 times heavier than seawater.

Mechanically dewatered sewage sludge, although only 20% solid, is dry to the touch. This is because the water is intracellular which means the water is contained within the cell walls of plants or organisms (Hightower et al. 1994, Attachment 7). Since this water is entrapped, it must be considered when calculating the particle specific gravity of sewage sludge. Figure 5.6.5.2-1 shows schematically a mechanically dewatered sewage sludge particle. The outer part of the particle is solid with a specific gravity of 1.2 and comprises 20% of the total particle. The inner part of the particle is water with a specific gravity of 1.0 and comprises 80% of the particle volume. When averaged together (0.2 X 1.2 + 0.8 X 1.0) the specific gravity of a sewage sludge particle is 1.04. When compared to the specific gravity of seawater (1.03), mechanically dewatered sewage sludge particles are 1.01 times heavier than seawater.

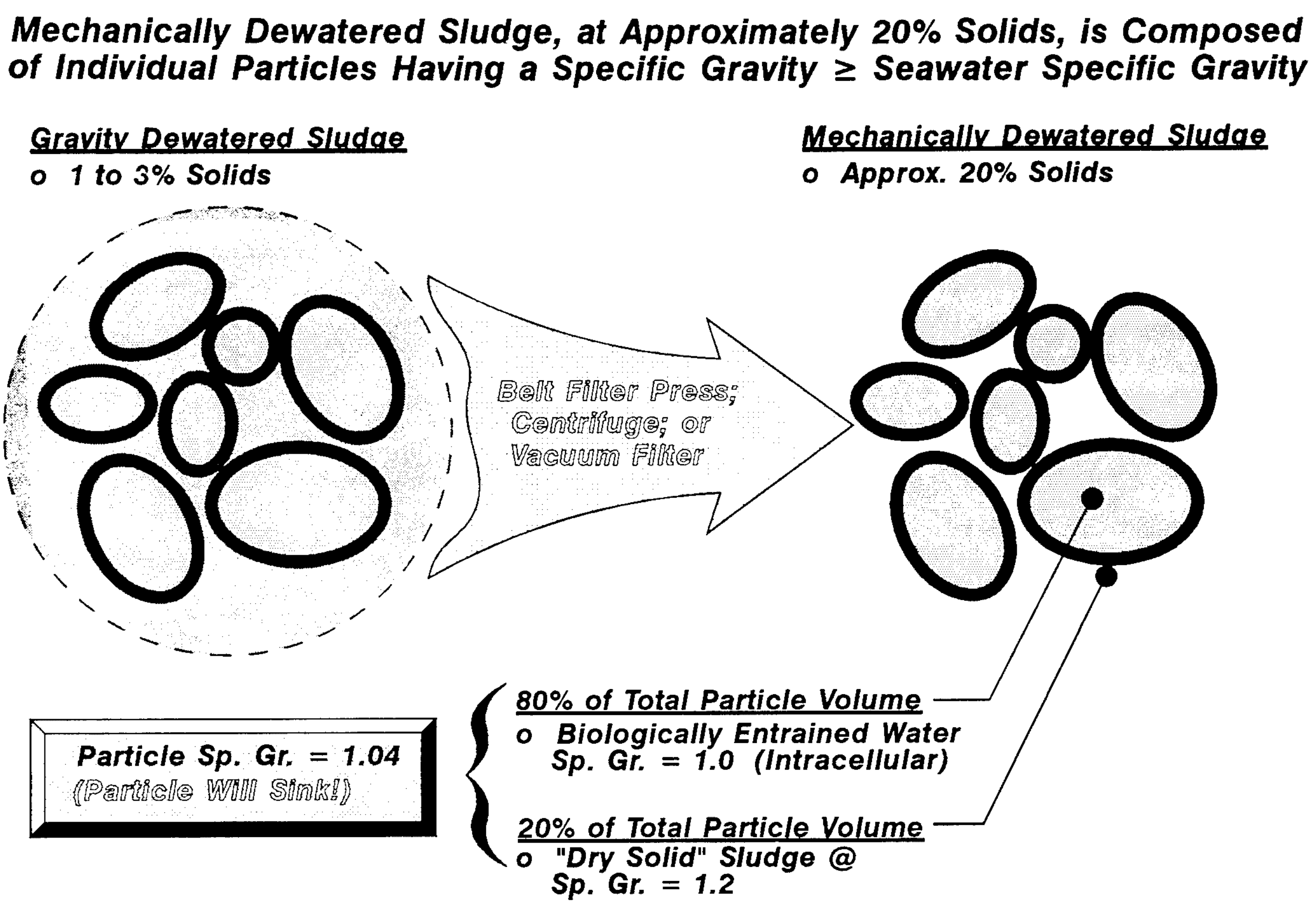


Figure 5.6.5.2-1
Sewage Sludge Particle Specific Gravity

5.6.5.3 SLURRY SPECIFIC GRAVITY

The slurry specific gravity, more properly termed the bulk specific gravity, of the waste dominated design criteria for all concepts, especially for the Pipe Riser. The slurry specific gravity is the ratio of solids to the total amount of the mixture. The slurry specific gravity can be calculated by volume or by weight. To calculate the specific gravity by volume, the following formula is used (Herbich 1980):

Equation 1:
$$C_v = \frac{S.G._m - S.G._f}{S.G._s - S.G._f}$$

To calculate the specific gravity of a slurry by weight, the following formula is used (Herbich 1980):

Equation 2:
$$C_w = \frac{S.G._s * C_v}{S.G._m}$$

Where: C_v = Concentration of solids by volume
C_w = Concentration of solids by weight
$S.G._s$ = Specific gravity of solids phase
$S.G._f$ = Specific gravity of water
$S.G._m$ = Specific gravity of mixture

Figure 5.6.5.3-1 shows the comparison of slurry specific gravity by weight, slurry specific gravity by volume, and apparent specific gravity by volume based on in situ volume, for a dredged material slurry containing a solid with a particle specific gravity of 2.65.

For the APWI project, specific gravity by weight was chosen for the calculations. Specific gravity by weight also can be calculated by substituting the "C_v" in Equation 2 with the right hand side of Equation 1. After algebraic manipulation, the standard slurry equation by weight is derived:

Equation 3:
$$S.G_m = \frac{S.G._f}{1 + C_w((S.G._f/S.G._s) - 1)}$$

A detailed breakdown of the slurry specific gravity by weight of the three waste streams is plotted in Figure 5.6.5.3-2. Specific gravity for the solid particles in the slurries are: 2.65 for dredged material, 1.2 for sewage sludge, and 2.5 for municipal incinerator fly ash. The slurry specific gravities in which the waste streams will most likely arrive at port, or be transferred at the dredging site are listed in Table 5.6.5.3-1. These slurry specific gravities were derived from Figure 5.6.5.3-2 using assumptions of pretreatment or dredging methods made in Section 5.6.5.1.

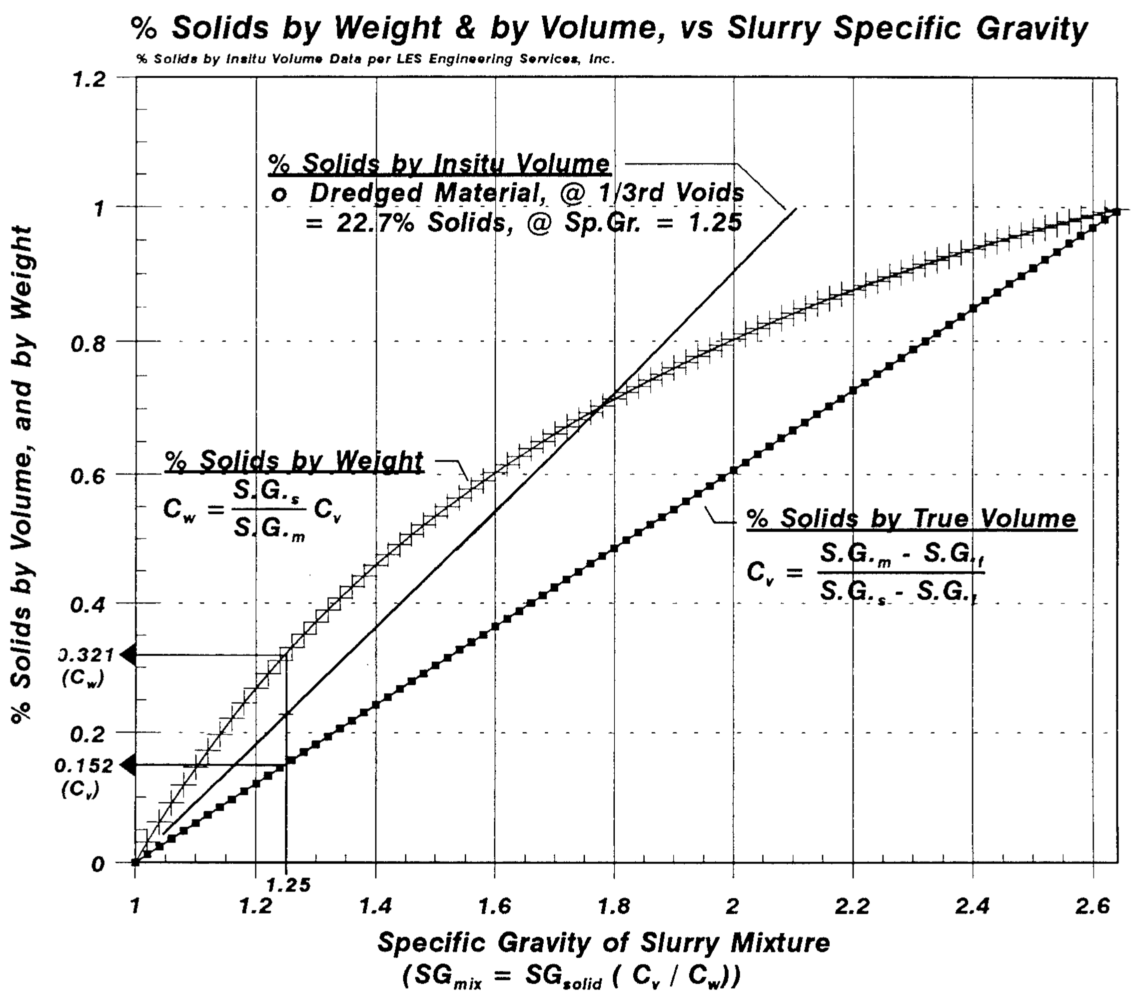


Figure 5.6.5.3-1
Comparison of Specific Gravity by Weight and by Volume for a Slurry

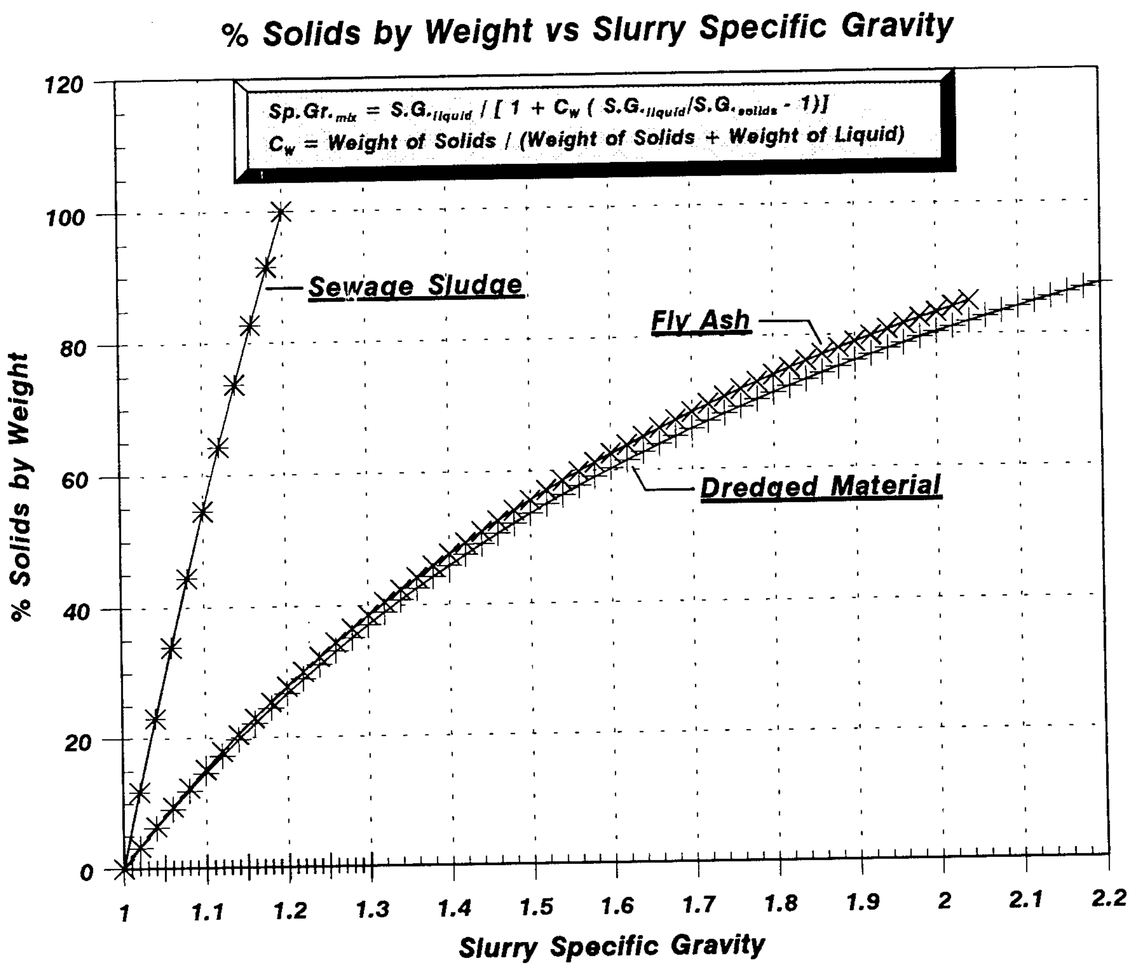


Figure 5.6.5.3-2
Percentage Solids by Weight versus Slurry Specific Gravity

WASTE STREAM	PERCENTAGE SOLID BY WEIGHT	SLURRY SPECIFIC GRAVITY
Dredged Material	32	1.25
Sewage Sludge	20	1.04
Municipal Incinerator Fly Ash	85	2.04

Table 5.6.5.3-1
Slurry Specific Gravities of APWI Waste Streams

Another issue when calculating the slurry specific gravity of dredged material is the void ratio, which is defined as the ratio of in situ volume of the voids to the in situ volume of the solids (Holtz and Kovacs, 1981). The void ratio is directly related to the porosity of the sediment which is expressed in percentage form. The volume of these voids which contain water is the degree of saturation for that sediment. If considering a fine grained sediment such as clay or silt, the void ratio will increase because of the disturbance of the sediments by the dredge equipment. If dredging coarse sediments such as loose sand, the dredging process may actually densify the material. The voids ratio effect on specific gravity can be determined experimentally, but for APWI, the dredge production equation was used which assumes an average of 22.7 percent solids in situ volume with a specific gravity of 1.25 (Turner, 1985). In the dredging industry, the in situ volume is the amount of volume the solids displace, which includes approximately 1/3 voids. This is also referred to as "apparent volume." For pumping calculations, the true solids volume is used which is 2/3 of the in situ volume (i.e., 22.7 X .67 = 15.2). Figure 5.6.3.2.-1 illustrates the relationship between true volume and in situ volume for dredged material. This production rate of 22.7% solids by volume is used as the basis of the minimum required flow rate, and is the operational goal for dredge pumps. Using this industry production standard, the ideal slurry specific gravity to interface with the APWI concepts is 1.25.

Since sewage sludge is only slightly heavier than seawater, it is recommended that it be mixed with fly ash to obtain a nominal specific gravity of 1.25, similar to dredged material. Sewage sludge at 20% solids has a slurry specific gravity of 1.04; fly ash at 85% solids has a slurry specific gravity of 2.04. To obtain a nominal slurry specific gravity of 1.25, four parts sewage sludge will be added with 1 part fly ash:

$$(4 \text{ X } 1.04 + 1 \text{ X } 2.04)/5 = 1.24$$

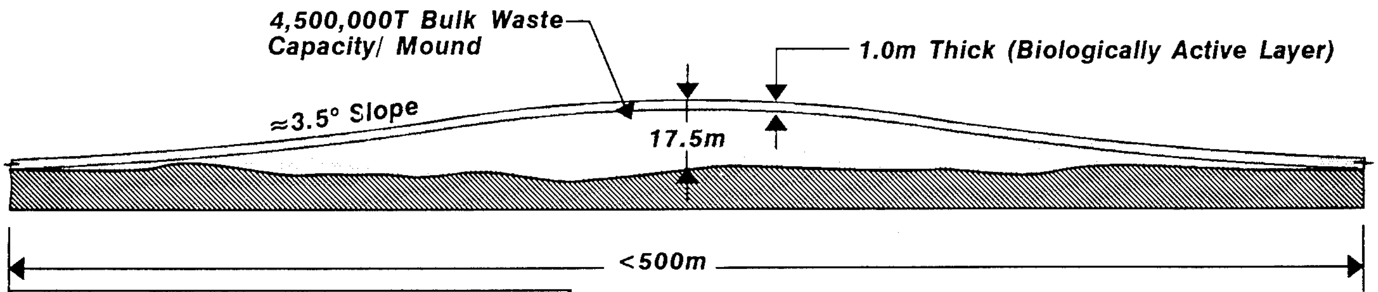
Ribbon blenders, which are hoppers with a heavy shaft and paddles, can be used to mix sewage sludge and fly ash at the port.

5.6.6 ISOLATION SITE CAPACITY

Isolation site storage capacity of 4.5 million tons is based upon four hundred 500 m X 500 m square grids, within a 10 km X 10 km designated site location, for a total of 1,800 million tons per Atlantic, Gulf of Mexico, or Pacific APWI site location. Figure 5.6.1-1 illustrates the mound geometry for a single 500 m X 500 m grid location. The upper illustration in this figure depicts the mound geometry if a Pipe Riser system is used to deposit loose bulk (slurryized) waste, and would result in a mound height of approximately 17.5 m, and mound slope of less than 3.5 degrees. The lower illustration depicts a slightly higher mound geometry, achievable with the use of geotextile bags providing waste containment. The higher mound would result from the inefficiency of the emplacement technique, and/or size of the bags. The Surface Emplacement concept would employ approximately 51 bags, of 500 metric tons. Final determination of mound capacity can be determined using computer simulation models which are currently in the final development stage. This simulation software is scheduled to be released to the public in October, 1994. Appendix F (Trip Report on 15th Annual Meeting and Technical Conference of the Western Dredging Association and the 27th Annual Texas A&M Dredging Seminar) gives additional detail on this software.

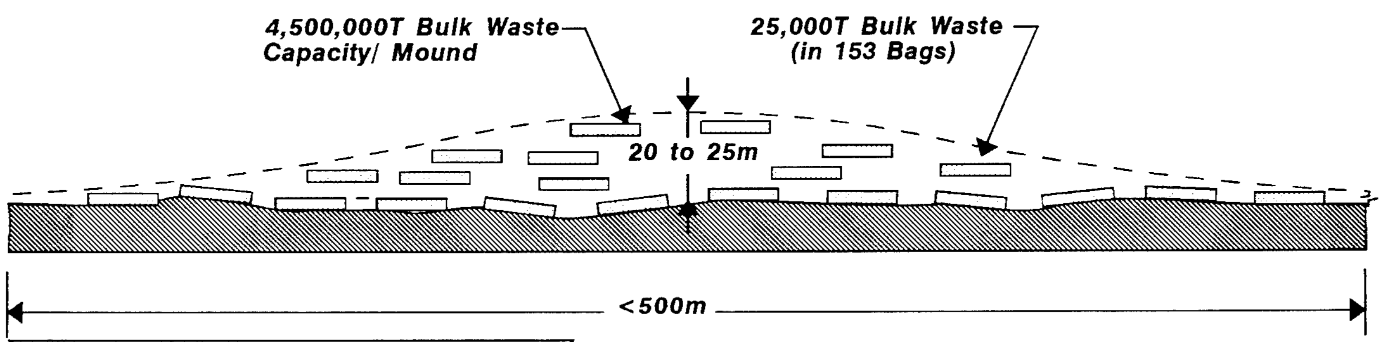
Abyssal Sea Floor Disposal Site Deposit Configurations with Maximum 100,000T/Day Bulk Waste Delivery to Site

Quad Riser: ≈1,800 Million Tons Capacity in 10 Km Sq. Site
(≈45 Days/Mound @ <4800T/Hr.)



88% of the Bulk Waste is Isolated from the Top 1.0m Layer of Cover

ROV Glider: ≈1,800 Million Tons Capacity in 10 Km Sq. Site
(≈45 Days/Mound @ <4800T/Hr.)



100% of the Bulk Waste is Isolated Due to Use of Geotextile Bags

Figure 5.6.6-1
Mound Characteristics

6.0 RELIABILITY ANALYSES

Two independent reliability analyses were performed for the Abyssal Plains Waste Isolation Project (APWI) for the purposes of identifying and assessing reliability risks associated with the APWI mission. In addition, the risk indices of the four concepts under evaluation to emplace Waste Stream Product at abyssal seafloor sites were compared.

The APWI mission is to transfer efficiently and safely, dredged material, sewage sludge, and fly ash from a port or harbor to a specified APWI site without waste loss in the intervening water column.

The ultimate objective of the reliability analyses is to provide data as input to the systems level analysis evaluating each concept for feasibility and to assist in selecting the best overall concept(s) for further evaluation.

The two analysis approaches are:

a) Fault Tree Analysis
b) Failure Modes, Effects, and Criticality Analysis (FMECA)

The four APWI concepts analyzed are:

a) Surface Emplacement
b) Direct Descent Disk
c) ROV Glider
d) Pipe Riser

In addition, analyses were performed for waste handling at port and for transportation to the APWI site. Early analysis effort indicated that there was no appreciable reliability risk difference for these mission segments between the four emplacement concepts.

6.1 FAULT TREE ANALYSIS

6.1.1 FAULT TREE METHODOLOGY

Fault Tree Analysis (FTA) is a graphical design analysis technique used extensively in Reliability, Safety, and Maintainability Engineering. It starts by identifying a top level undesired event (e.g., a failure mode or a safety hazard) and identifying how the top event can be caused by individual or lower level events or failures.

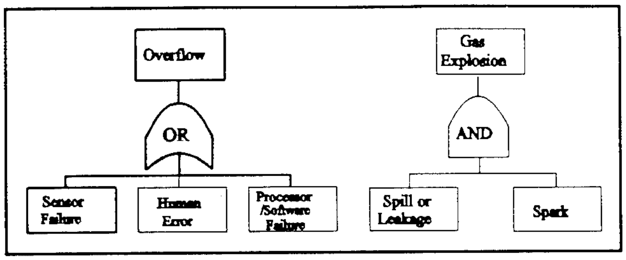


Figure 6.1-1
FTA Symbol Examples

An FTA uses industry standard symbols. Figure 6.1-1 (FTA Symbol Examples) shows, using examples from the Abyssal Plains Waste Isolation Project Fault Tree, the three symbols used in that analysis. These are:

a) Rectangle (or square) showing an event.

b) A Logic "OR" shows how multiple independent events can lead to a higher level event. The word "OR" is printed in the appropriate symbol for this illustration. In the example, a sensor failure or a human error or a processor/software error can lead to an overflow condition.

c) A Logic "AND" (also printed in the example symbol) shows how multiple or combined events can lead to a higher level event. This example shows that a spill or leakage and a spark, together, can lead to a gas (Methane) explosion.

A different FTA must be generated for each identified top event requiring analysis.

6.1.2 FAULT TREE RESULTS

The top events chosen for the APWI Project are failure of the three mission segments for the configurations under evaluation. The three mission segments are:

a) Waste Stream Product Loading at Port
b) Transit From Port to APWI Emplacement Site
c) Emplacement Operations

Early in the analysis process, it became apparent that the four concepts shared essentially common FTA's for the first two mission segments. Figures 6.1.2-1 and 6.1.2-2 are the common first two segment fault trees.

Figure 6.1.2-1 is the FTA for "Waste Stream Handling at Port". Six top level undesired events are identified with probable causes shown. The bold lines and events are those identified by experience as the critical event paths requiring close control during design and development. For example, these fill sensor failures lead to overflow during storage container fill, excessive hydraulic pressure cause line rupture, and transfer mechanism failures could lead to waste spill/leakage. Note that this fault tree covers two different transfer approaches, i.e., mechanical (buckets, conveyor) and hydraulic (pumping).

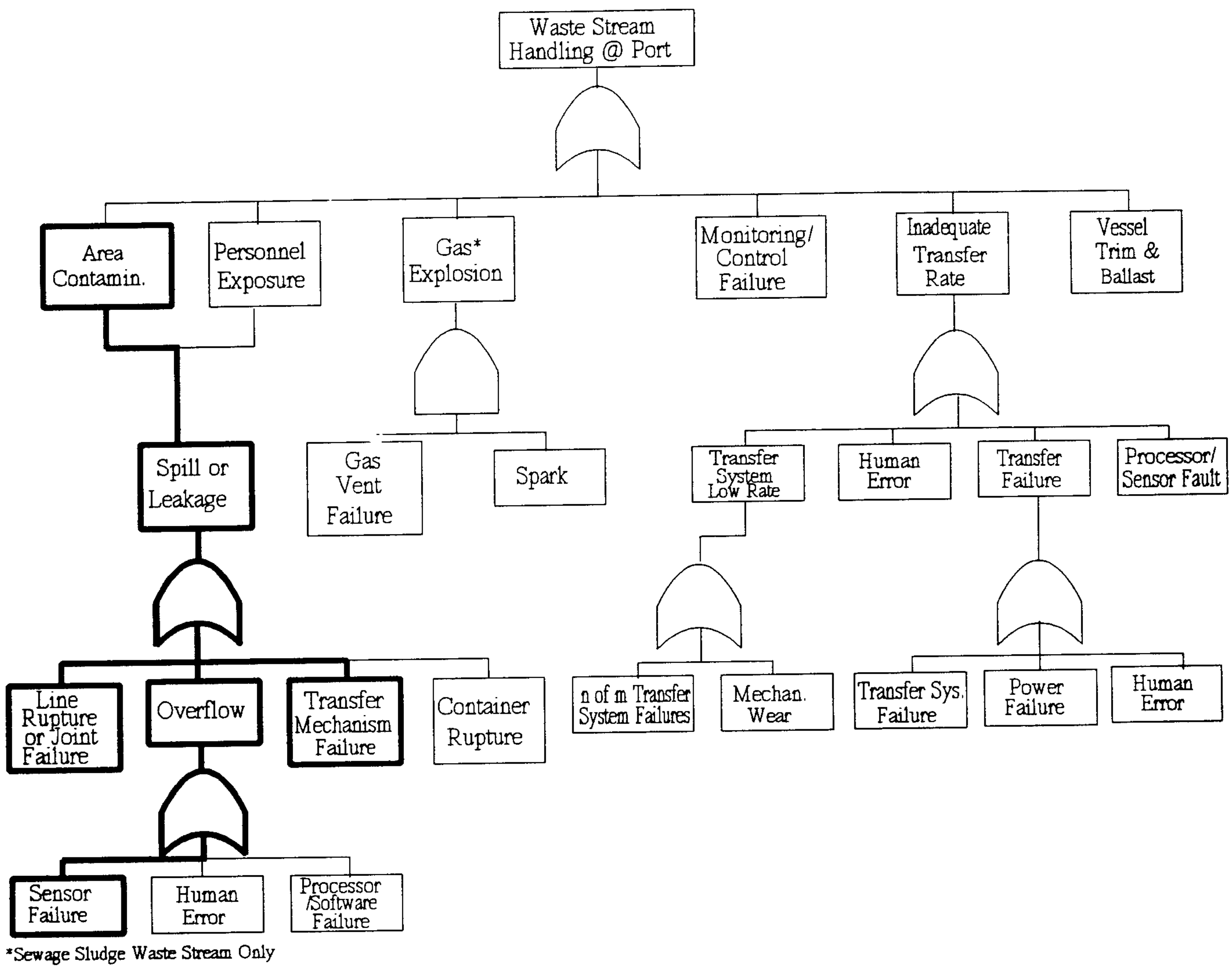


Figure 6.1.2-1
Waste Handling at Port FTA

Figure 6.1.2-2 is the common FTA for the "Transport to Site" mission segment. This FTA identifies seven undesirable top level events for analysis. Note that the queuing failure is considered most critical. This event is most likely to be caused by either a dispatcher error, bad weather, or inadequate system capacity. System capacity failure could be avoided by sizing the concept for worst case traffic conditions. Designing to such a requirement, however, would lead to an inefficient and unnecessarily expensive concept. Also note that none of the events likely to lead to a queuing failure results from a hardware failure. Had the analysis been limited to a FMECA, risks associated with this system level "failure" might have been missed.

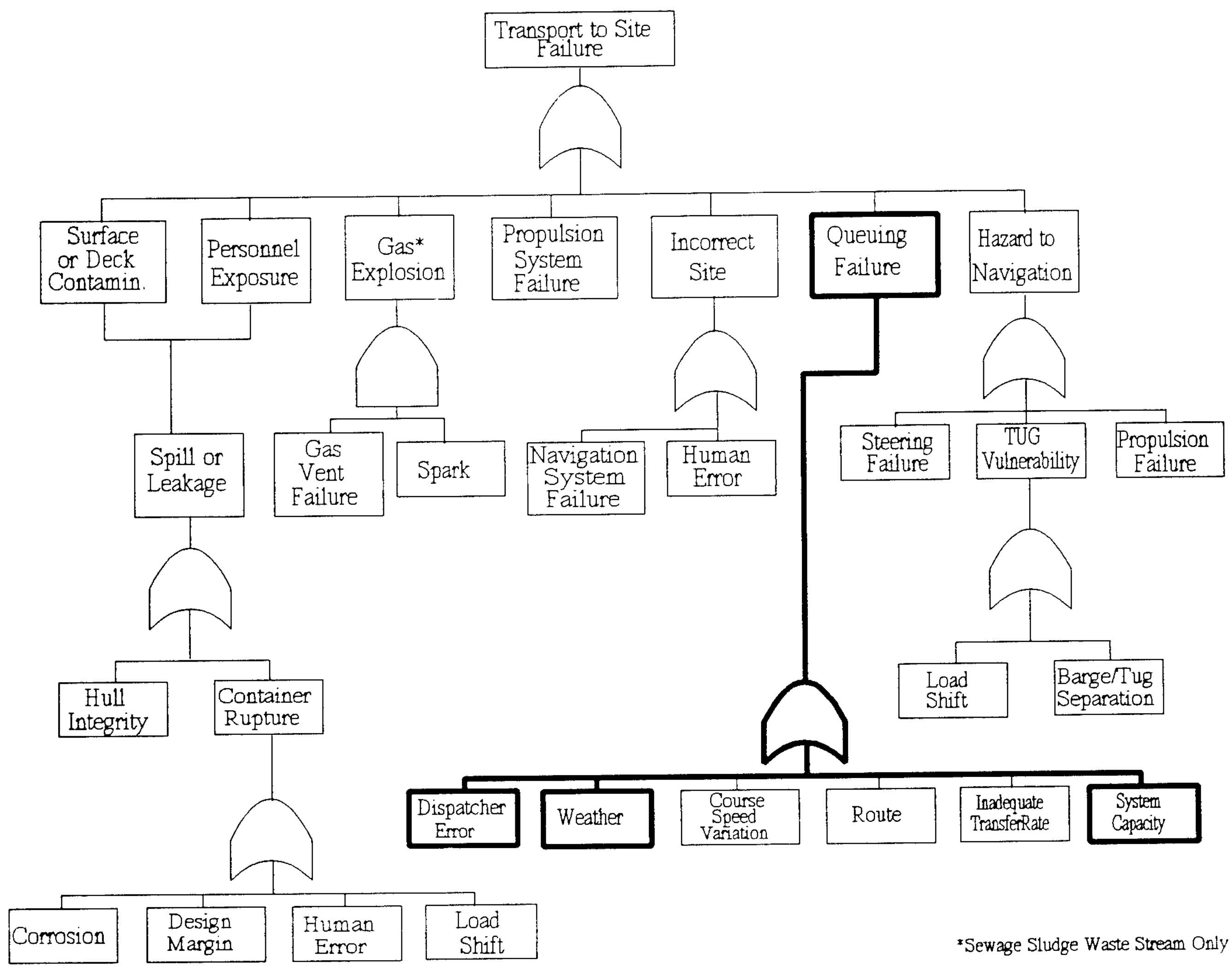
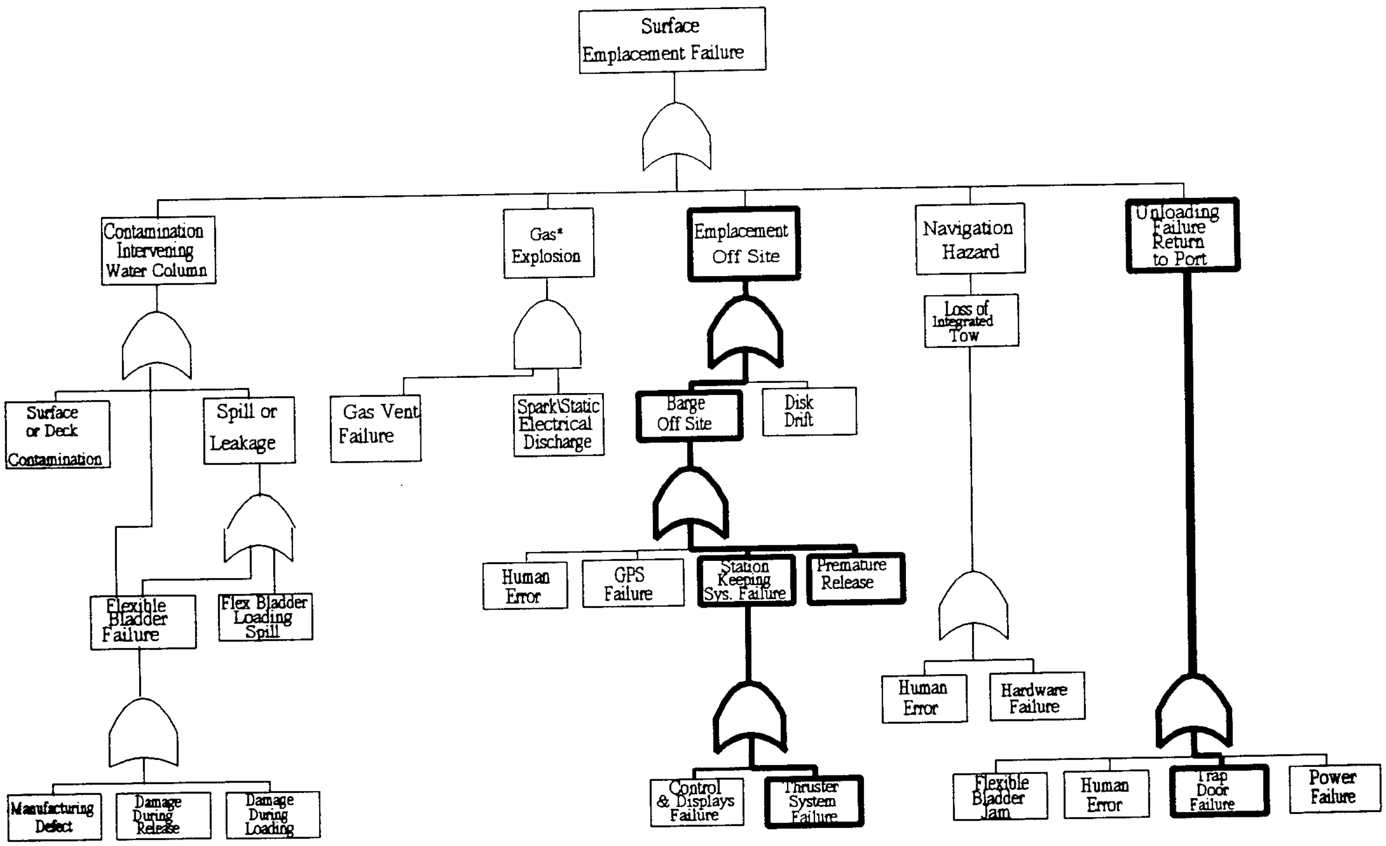


Figure 6.1.2-2
Transport to Site FTA

The first emplacement concept fault tree may be found in Figure 6.1.2-3, Surface Emplacement. This concept is one of the simplest. The major risk associated with this approach is that of emplacement off-site resulting from either a station keeping failure or a premature release of some of the waste cargo. The most likely cause of the former is related to thruster system reliability. Bags ripping at the surface is a current problem.



* Sewage Sludge Only

Figure 6.1.2-3
Surface Emplacement FTA

The next emplacement concept examined is the Direct Descent Disk. Its FTA is in Figure 6.1.2-4. As with the surface emplacement concept, emplacement off-site is a risk that requires attention to mitigate. An additional risk, with the concept, is the loss of the Disk itself. The two most significant causes of this undesired event are failure to release the cargo preventing the Disk to resurface or the inability to locate the Disk upon surfacing.

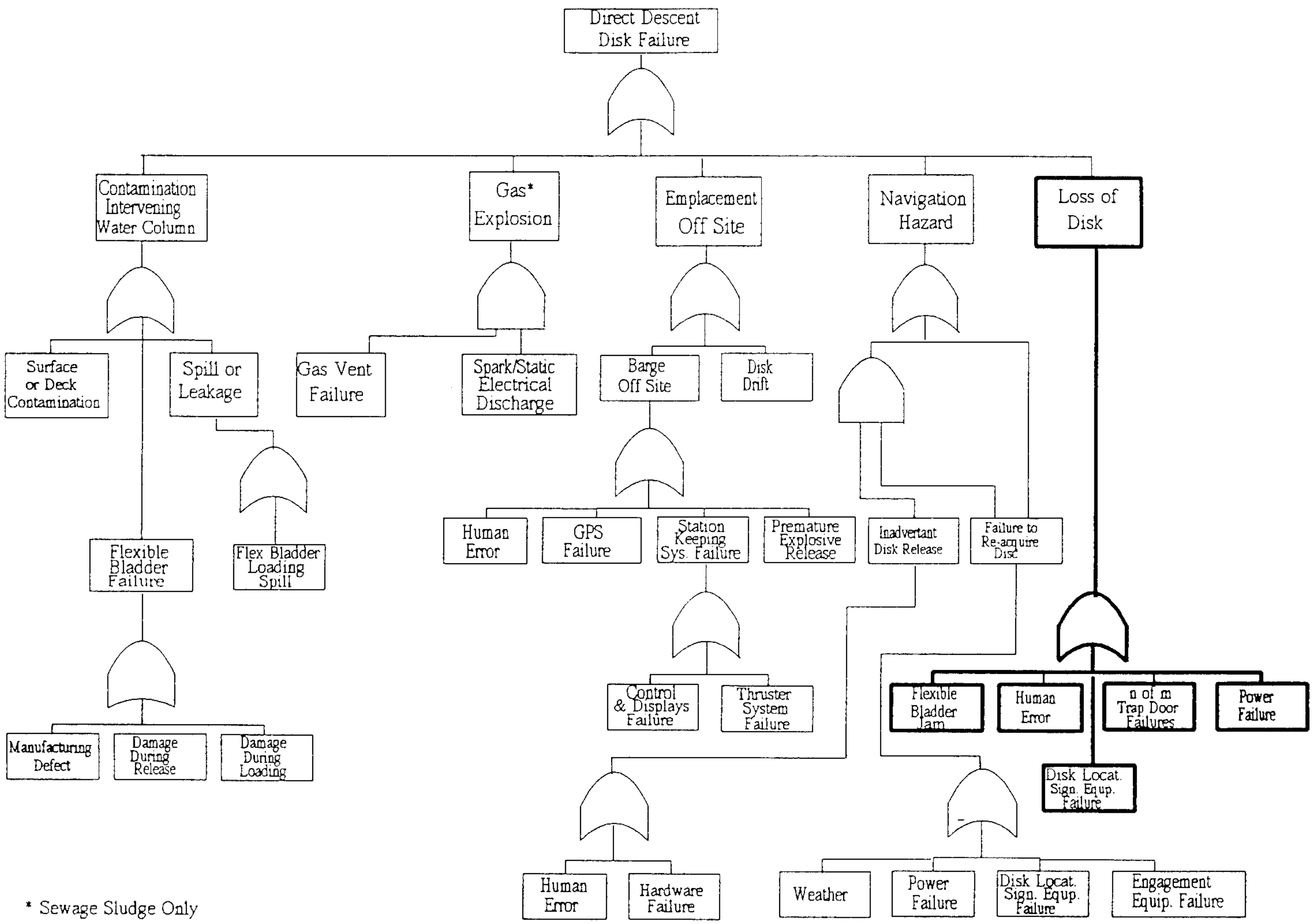


Figure 6.1.2-4
Direct Descent Disk FTA

The third emplacement approach is the Remotely Operated Vehicle (ROV) Glider. Its FTA may be found in Figure 6.1.2-5. The major reliability risk associated with this approach is loss of the ROV Glider either through the loss of flight control, inability to re-acquire it following release of its cargo, or the failure of the Glider to emplace its entire load preventing it from resurfacing.

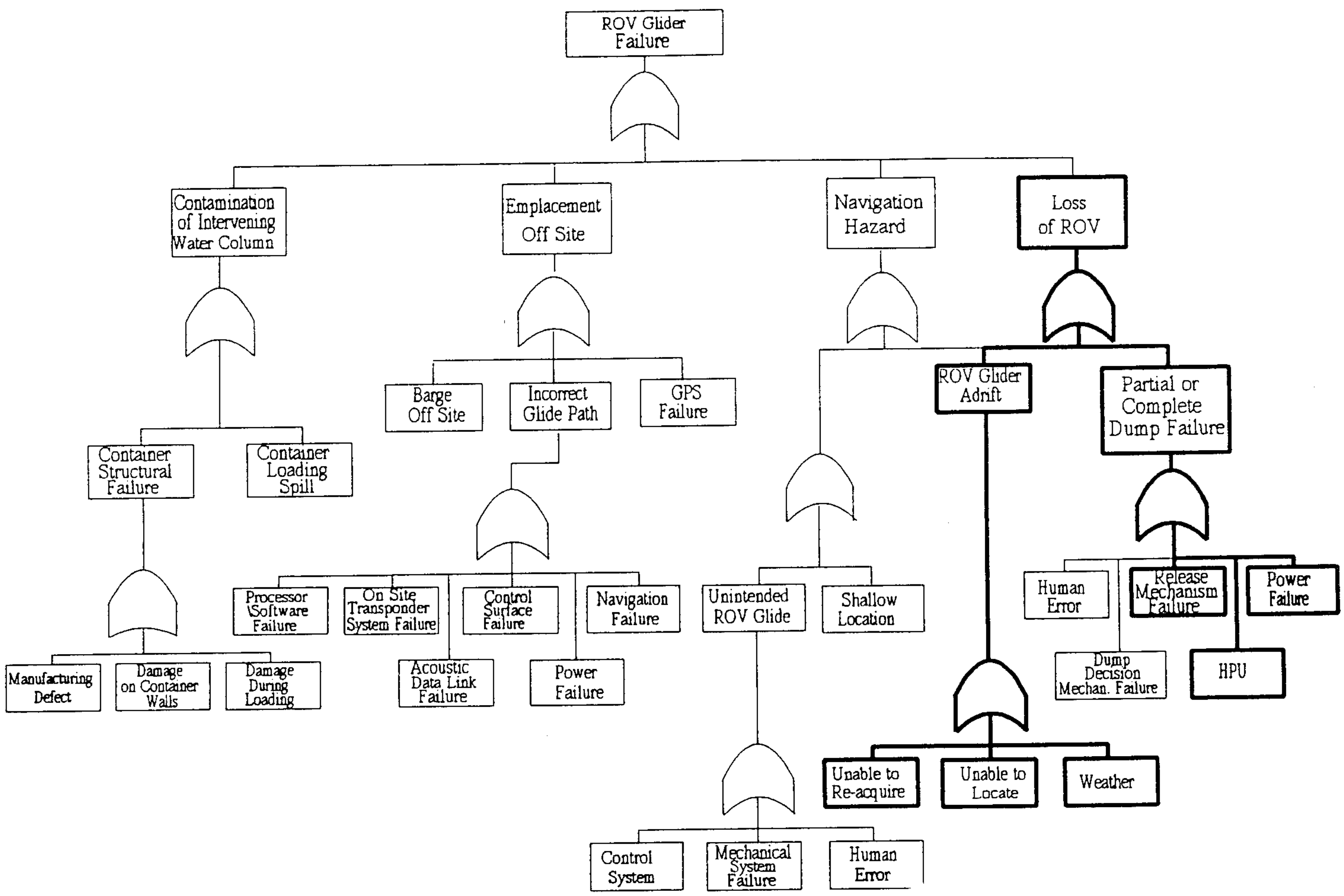
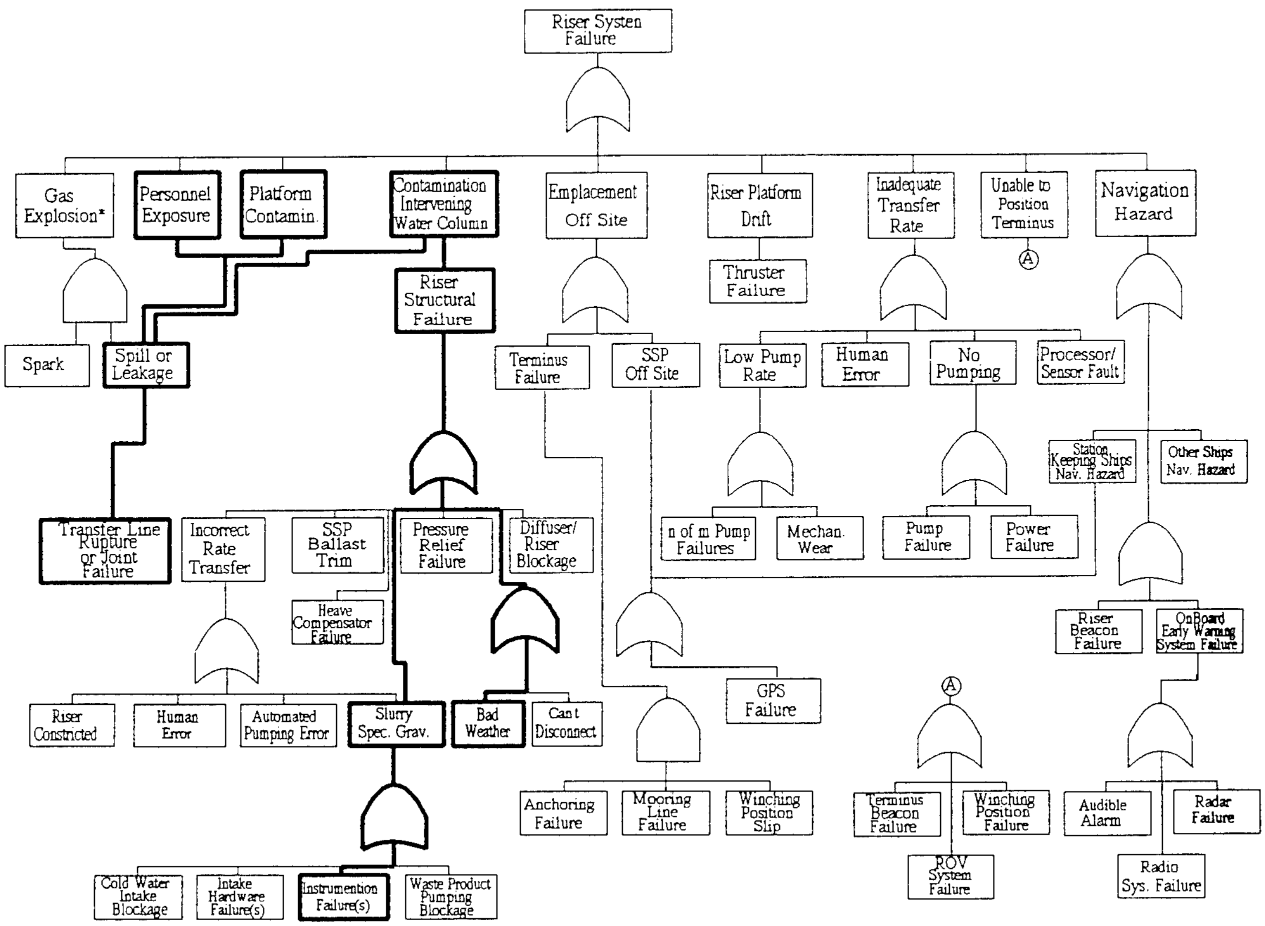


Figure 6.1.2-5
ROV Glider FTA

The final approach studied is that of the Pipe Riser. Its FTA may be found in Figure 6.1.2-6. This is the most complex concept studied, as evident in the FTA. The major risks associated with this approach are "open" waste loss issues. That is spills or leakage resulting from hydraulic line ruptures or failure of the riser pipe itself. While instrumentation failure is the most likely failure leading to structural failure, it is clear that there are a number of less probable but finite additional potential causes of riser structural failure.



* Sewage Sludge Only

Figure 6.1.2-6
Pipe Riser FTA

6.1.3 FAULT TREE CONCLUSIONS

Fault Trees have been generated for all APWI mission scenario and segment elements. The more complex the element, the more realistic are the potential causes of failure. No major risks have been identified that can not be mitigated either through added redundancy or improving operating procedures, e.g., shut down operations in bad weather to secure equipment and avoid damage or waste spillage.

Although the risks in the fault tree were not "quantified" by either severity or probability of occurrence, it is clear that the riser approach presents more reliability related risks than any other approach. The remainder of the concepts appear to have equivalent risk. Also note that the risks of most concern in transporting the Waste Stream Products from shore to the isolation site are primarily related to external conditions and not the hardware involved.

6.2 FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

6.2.1 FMECA METHODOLOGY

The Fault Tree Analysis of Section 6.1 is a top down analysis that first identifies undesired events and then isolates all possible (or probable) causes. It is performed for specific undesired events including failures, operating procedures, human errors, and external events such as currents or bad weather.

A Failure Modes, Effects, and Criticality Analysis (FMECA) is usually performed bottoms-up. It analyzes failures caused by hardware, software, and sometimes human errors. The FMECA is generated from a different set of questions than the FTA. The FTA is performed by asking "what could cause this event"? The FMECA, on the other hand, is performed by asking "If this fails, what is the impact on the system? Can I detect it? Will it cause anything else to fail"? If so, the induced failure is called a secondary failure. FMECA's may be performed at the hardware or functional level or, as for this study, may be performed on a combination of both.

There are some risks unique to the Riser configuration that are not reflected in either the FTA or the FMECA since they do not result from a hardware/software failure. These include those associated with Riser construction, on-site installation, and maintenance at sea. These are program risks rather than reliability risks captured in this analysis.

6.2.2 FMECA ANALYSIS

This Failure Modes, Effects, and Criticality Analysis was performed in accordance with the intent of MIL-STD-1629A (Procedures for Performing a Failure Mode, Effect, and Criticality Matrix). The results of FMECA is provided in Appendix G for each individual concept as well as the waste stream handling at port and the transport to site.

The approach to generating the APWI FMECA was to first list all major components and mission functions of interest. Then, by examining concept block diagrams and through working group "brain-storming" sessions, the function of each was identified. Next, all reasonably possible failure modes of components of functions and their effects on the mission and environment were analyzed.

The method of fault detection was also documented. This input is valuable for both risk mitigation and failure containment purposes. For example, if a series of life impacting stresses are introduced through an unusual event such as bad weather or if a waste stream line begins to rupture, the faster it is detected, the faster the system can be shut down to prevent or limit environmental damage. Compensating provisions are identified to determine more about the impact of the failure considered and to identify existing or desired mitigating system features. If there are redundant pumps, for example, the significance of the failure is less than if the system depends on a single pump.

Assigning severity categories and probabilities of failure was the final step in the APWI FMECA process. These were assigned for each failure mode and significant cause.

Each failure mode was assigned a qualitative probability value from the probability of occurrence (PO) levels shown in Table 6.2.2-1. Each failure cause and effect was subjectively assigned a severity class (SC) from the scale shown in Table 6.2-2.2. Taken together the PO and SC determine each element's criticality or risk index.

Table 6.2.2-1
Qualitative Probabilities of Occurrence

Level	Definition
Level A - Frequent	A high probability of occurrence during the item's operating lifetime.
Level B - Reasonable Probable	A moderate probability of occurrence during the item's operating lifetime.
Level C - Occasional	An occasional probability of occurrence during the item's operating lifetime.
Level D - Remote	An unlikely probability of occurrence during the item's operating lifetime.
Level E - Extremely Unlikely	A failure whose probability of occurrence is essentially zero during the item's operating lifetime.

Table 6.2.2-2
Severity Class

Level	Definition
Category I - Catastrophic	A failure that may cause death, a major waste exposure, major waste spill, or loss of major portions of the APWI concept.
Category II - Critical	A failure that may cause severe injury, significant personnel exposure or intervening water column waste loss, major system or facility/component damage that will result in significant system downtime.
Category III - Marginal	A failure that may cause minor injury, minimal personnel exposure or intervening water column waste loss, minor component or facility/component damage that will result in system downtime.
Category IV - Minor	A failure that is not serious enough to cause injury, waste exposure, or equipment damage, but will result in substandard system operation. Repair can be scheduled at normal scheduled maintenance intervals.
Category V - No Effect	A failure that has no impact on system operation and does not result in unscheduled downtime.

Identification of the risk index for each failure cause analyzed is the "meat" of the FMECA. These outputs are used in determining viability and necessary risk mitigation. Table 6.2.2-3 is a matrix showing the 25 possible combinations of the PO and SC. For example, criticality II-D corresponds to elements whose failure modes will occur with a remote likelihood, while resulting in a critical situation. The criticalities that appear "above" the gray area (labeled with "C") correspond to critical issues. Those criticalities "below" the gray area (labeled with "N") correspond to components that are not critical items. Due to the uncertainty in determining the PO and SC values, a band (main diagonal) of five criticalities correspond to components that are potentially critical items; these are labeled with "P" and appear in the gray area.

Table 6.2.2-3
Probability of Occurrence/Severity Class (Criticality)
Criteria for Critical Elements

SEVERITY	CLASS	PROBABILITY OF OCCURRENCE A	B	C	D	E
	I	C	C	C	C	P
	II	C	C	C	P	N
	III	C	C	P	N	N
	IV	C	P	N	N	N
	V	P	N	N	N	N

where:

C indicates Critical Issues
P indicates Potential Critical Issues
N indicates Non-Critical Issues

To compare risk levels of alternate approaches, numerical weightings were assigned to both severity class and probability, as in Table 6.2.2-4, multiplied for each major failure/failure cause to obtain a risk index, and summed for each configuration approach and mission segment.

Table 6.2.2-4
Risk Weighting Factors

Severity Class	Weighting	Probabilities of Occurrence
Category I	4	A
Category II	3	B
Category III	2	C
Category IV	1	D
Category V	0	E

6.2.3 FMECA CONCLUSIONS

The calculated weighted risk indexes are as follows:

a) Waste Stream Product Handling @ Port	29
b) Transit to Site	14
c) Pipe Riser	147
d) Surface Emplacement	34
e) Direct Descent Disk	95
f) ROV Glider	101

This risk ranking indicates that the Surface Emplacement concept offers the least operational risk, while the Pipe Riser concept is clearly the concept with the highest risk. The ROV Glider and the Direct Descent Disk concepts basically rank equal.

7.0 COMPARISON TO SYSTEM REQUIREMENTS

The defined concept capabilities were compared to the system level requirements including the system performance/operational requirements and the environmental regulatory requirements generated earlier in this study (see Marcy et al. 1994). Some of the system performance/operational requirements were modified during the concept definition phase and items left "TBD" were clarified herein. The following lists these performance/operational requirements:

1a. System Capability: Greater than 2.5 Million Metric Tons per Year per Port. This was determined in section 5.6.1. The Tethered concept did not comply, with capability to emplace only 1.13 million metric tons/year/port.

1b. System Capability: Less than 1800 km (1000 nmi) Transiting Distance from Coastal Ports. This value is a core requirement for this study. All concepts comply. The average transiting distance from 23 Atlantic, Gulf of Mexico, and Pacific coastal ports to designated APWI sites is 1060 km (575 nmi).

1c. System Capability: No Exposure of Waste Stream Products to the Intervening Water Column, Including Leakage and Spill Prevention Design Features. This is a core requirement for this study. All APWI concepts comply.

1d. System Capability: Static Electricity Dissipation Design Features. Safety considerations by definition are incorporated into each concept to assure adequate grounding between the vessel and dockside facilities and/or the vessel and emplacement facilities. Dangerous levels of static charge could be developed as a result of processing plant connectivity and/or material flow through conductive bulk waste transfer lines or conveyances.

1e. System Capability: Validation and Verification. Specific requirements for validation and verification have been established as a result of the APWI system detailed concept definition(s) risk assessment for the concepts. The Reliability Analysis results provide the means to identify/make this risk assessment. The Fault Tree Analysis and the Failure Modes, Effects, and Criticality Analysis (FMECA) identify subsystem element critical areas for each of the concepts. The need for validation and verification is a direct result of determination of "high" engineering or developmental risk. Specific critical areas of each of the concepts are described in Section 6.0, with recommendations provided for the nature and the scope of the experimental validation process necessary to demonstrate conceptual feasibility. All concepts possess at least one (or more) critical areas requiring experimental validation to confirm anticipated performance/operational characteristics.

1f. System Capability: Range Safety Design Features. Range Safety issues are primarily focused on two of the four concepts, the ROV Glider and the Direct Descent Disk concepts. Tracking of the respective vehicles through both the descent and ascent phase of the emplacement process is imperative to ensure that standoff distances between the host vehicle and the ascending vehicles is maintained at adequate margins (e.g., >1000 m), to avoid collision. Both of these concepts complete the descent and ascent phase in approximately 1 hour, with "average" current values of <0.5 knots from the surface to the abyssal seafloor. Consequently, station-keeping by the host vehicle at the point of release, yields a point-of-return approximately 1000 m "downstream". Additionally, means must be provided to alert any traffic in the area to the presence of the drifting vehicle, prior the its recapture by the host vehicle.

2. Transiting Speed: 6.2 m/s (12 knots), Minimum. A best estimate for achievable speed is 16.5 knots for "large" capacity bulk carriers, and approximately 15 knots for integrated tow barge/scow configurations. The

12 knot value originally specified in the System Requirements Report (Marcy et al. 1994) is a conservative value selected to account for typical ocean-going tugs that might be employed for an APWI concept. All concepts have 15 knot capability.

3. Operational Depth: 6700 m, Maximum. This value provides a 10% margin of safety versus designated APWI site locations, and reflects present day capability of special Navy and commercial ROV work vehicles to operate at equivalent depths. All concepts (excluding Surface Emplacement--not required) meet this requirement.

4. Emplacement Accuracy: <0.25 km². The goal for emplacement accuracy is to minimize the active emplacement area and to facilitate monitoring. A 500 m X 500 m target area located at 6700 m depth is a practical target for all concepts evaluated. All concepts are potentially capable of meeting this requirement, with anticipated positioning accuracy for bulk waste emplacement as follows:

- Surface Emplacement: < 500 m diameter "Shot-Group"
- ROV Glider: < 50 m X 150 m (150 bags, 167 metric tons each)
- Direct Descent Disk: < 40 m diameter (169 bags, 34.6 metric tons each)
- Pipe Riser: < 15 m diameter, location of lower terminus assuming single or multiple point mooring.

5. Reliability: Given that all of the proposed systems are in the conceptual phase only, it is not possible to directly determine system reliability via the combination of component reliabilities. Instead, by assigning values of acceptable Operational Availability (A_o) and expected Mean Time To Repair (MTTR), the allowed Mean Time Between Failures (MTBF) can then be calculated. The relationship between A_o, MTTR, and MTBF is:

$$A_o = MTBF/(MTBF + MTTR)$$

MTTR values were based upon OTECH's relevant operational experience with marine equipment and the relative complexity of each of the concepts. For values of A_o, Surface Emplacement was used as the baseline concept, with all other concept's A_o values derived from this value. The rationale for selecting A_o and MTTR for each concept is described below and summarized, including calculated MTBF values, in Table 7.0-1.

- Surface Emplacement: A value of A_o = 0.950 was chosen based on the minimum value that was estimated to be acceptable for this type of operation. This assumes that 5% of the trips/year will not be successful due to system reliability problems. This value does not represent the operational availability that may be possible with this design. A value of 36 hours for MTTR was selected based upon related experience with marine handling equipment.

- ROV Glider: A value of A_o = 0.995 was selected by assuming that 0.5% of the maximum trips/year cannot be performed. This number is greater than the Surface Emplacement value because of potential asset loss due to failure to resurface. The MTTR is the same as for Surface Emplacement.

- Direct Descent Disk: A value for A_o = 0.976 was selected based upon comparable characteristics versus that of the ROV Glider but adjusted to account for five redundant units. For example, loss of a single unit only affects 20% of the equivalent mission capability. The MTTR is the same as for Surface Emplacement.

- Pipe Riser: A value for A_o = 0.988 was selected based upon comparison to Surface Emplacement and noting that the Pipe Riser services four transporters. For example, to realize an A_o of 0.950, we can permit each transporter to be non-operational 1.25% of the maximum trips/year (4 ea. X 1.25% = 5%).

Table 7.0-1
Calculated MTBF for System Concepts

Concept	A_o	Selected MTTR	Calculated MTBF
Surface Emplacement	0.950	36	720
ROV Glider	0.995	36	7200
Direct Descent Disk	0.976	36	1440
Pipe Riser	0.988	72	6000

As shown in Table 7.0-1, the minimum A_o and maximum allowable MTBF numbers required to meet the reliability rationale described above are, in some cases, quite high. The only way to successfully meet these values are to design redundancy into the systems. This extra redundancy will primarily affect development time and costs associated with designing and testing these redundant features. However, the production cost impact is not expected to be of significant, since the electromechanical devices are not the primary cost drivers in these structurally dominated systems.

6. Maintainability: Allowable MTTR values were selected based on system complexity.

7a. Environmental: Operation in Sea State 5 Conditions. Concepts must be capable of operation under sea state 5 conditions. Any reduction in capability would result in a significant reduction in the available number of operational days, by 25 to 50%, and is dependent upon the site location. Deep water operations in sea state 5 conditions are typical of current Navy and commercial operations. All APWI concepts are capable of operation in sea state 5 conditions.

7b. Environmental: Survivability is Sea State 8 Conditions. This is required for open ocean operations, far from shore, and reflects the inability of concepts to "run for cover". All concepts, except for the Pipe Riser, are capable of avoiding extreme weather conditions by remaining in port, or heading out of the area affected. The Pipe Riser employs a Spar Buoy Upper Terminus, and possesses similar structural and stability characteristics to that of current open ocean unmoored Semisubmersible Platforms. These conditions are wave heights of 34 m (110 ft), wind speeds of 59 m/s (115 knots), and currents up to 1.3 m/s (2.5 knots) (with dynamic positioning thrusters).

7c. Environmental: Current <0.8 m/s (1.5 knots) on Surface, and <0.4 m/s (0.75 knots) on Abyssal Seafloor. These values for currents are based upon 500 data points, which identify worst-case conditions scattered around the world's oceans. All concepts meet this requirement.

7d. Environmental: Hydrostatic Pressure <67 MPa (<9700 psig). Refer to Requirement 3. Applicable to three of the four concepts (not applicable to Surface Emplacement).

7e. Environmental: Temperature 0°C to 49°C. This temperature range reflects typical operating temperature extremes for Navy and commercial ROV handling systems and work platforms. All concepts can meet this requirement.

8. Waste Stream Compatibility: (Non-Hazardous). The selected values reflect waste stream characteristics as delivered to the port facility from various sources. Section 5.6.5 summarizes values for each waste stream and

the potential dewatering values, or percent solids versus bulk specific gravity that must be accommodated by the Transporter System. All APWI concepts meet these requirements. It should be noted that the Pipe Riser requires slurryizing of the bulk waste from the transporter, using dilution seawater from 760+ m depths, to reduce the waste bulk specific gravity to a value of approximately 1.014. This value is required to achieve safe operating conditions/maintain riser structural integrity under gravity flow conditions down the discharge lines.

9. Design Requirements: As Listed, for any New or Modified Ocean-going Equipment. This equipment must meet established standards for design, fabrication and operation. All APWI concepts employ off-the-shelf, commercially-available hardware.

The Tethered Container concept was the only concept which could not be engineered to achieve the desired system capability. Each tethered container can emplace only 0.5 million tons per year; whereas, the goal is for each system to emplace 2.5 million tons per year. This concept's emplacement quantity capability is limited by existing tether line diameters, tether lengths, and winch sizes.

The summary of the comparison of the concepts to the System Level Requirements is shown in the compliance matrix in Figure 7.0-1.

Compliance Matrix: APWI System Concepts vs System Requirements

	System Requirements	Surface Emplacement	ROV Glider	Direct Descent Disk	Pipe Riser
1.0:	General System Level Criteria:				
1a:	System Capability ≈ 2.5 Million Metric Tons/Year (1)	2.60 Mt/Yr.	2.48 Mt/Yr.	2.38 Mt/Yr.	2.33 Mt/Yr.
1b:	Transiting Distance from Coastal Ports ≤ 1000 Nm	Meets	Meets	Meets	Meets
1c:	No Exposure of Waste Stream Products to Intervening Water Column, & Leak/ Spill Prevention	Meets	Meets	Meets	Meets
1d:	Static Electricity Dissipation Design Features	Meets	Meets	Meets	Meets
1e:	Validation & Verification of High Risk Elements	Low Risk	Med. Risk	Med. Risk	High Risk
1f:	Range Safety Level of Complexity	Very Low	High	High	Very High
2.0:	Transiting Speed ≥ 12 Knots	15 Knots	15 Knots	15 Knots	15 Knots
3.0:	Operational Depth Capability Up to 6700m	Meets	Meets	Meets	Meets
4.0:	Emplacement Accuracy vs 500m X 500m Target Area	≤ 500m Dia.	≤ 50m X 150m	≤ 40m Dia.	≤ 15m Dia.
5.0:	Reliability, Mean Time Between Failure (MTBF)	720 Hrs.	7200 Hrs.	1440 Hrs.	6000 Hrs.
6.0:	Maintainability, Mean Time to Repair (MTTR)	36 Hrs.	36 Hrs.	36 Hrs.	72 Hrs.
7a:	Environmental, Operation in Seastate 5 Conditions	Meets	Meets	Meets	Meets
7b:	Environmental, Survivability in Seastate 8 Conditions	Meets	Meets	Meets	Meets
7c:	Environmental, Currents at Surface ≤ 1.5 Knots, and ≤ 0.75 Knots on Abyssal Seafloor	Meets	Meets	Meets	Meets
7d:	Environmental, Hydrostatic Pressure ≤ 9700 psig	Meets	Meets	Meets	Meets
7e:	Environmental, Temperature 0 Deg. to 49 Deg. C	Meets	Meets	Meets	Meets
8.0:	Waste Stream Interfacing Compatability	Low Risk	Low Risk	Low Risk	Low Risk
9.0:	Capability to Meet Existing Design Standards/ Reqts.	Low Risk	Low Risk	Low Risk	Low Risk

(1) *Based Upon 25,000 DWT Transporter X No. Trips/Year, @ 100% Operational Availability*

Figure 7.0-1
System Level Requirements Compliance Matrix

8.0 CONCLUSIONS

Four of the five concepts proposed for use as APWI emplacement systems were determined to be technically feasible. These four concepts are:

- Surface Emplacement
- Direct Descent Disk
- ROV Glider
- Pipe Riser

The Tethered Container approach was found to be technically not feasible to emplace the volumes of material requiring isolation for the three waste streams studied.

During the detailed concept definitions and reliability analysis, several critical areas were identified for each concept that warrant additional study, modeling and/or experimentation. Because of the scope of this study, some issues from the four technologically viable APWI concepts are unresolved pending further experimentation. It is expected that the experiments or computer/physical models will confirm predictions made in the technical report. Tables 8.0-1 through 8.0-4 summarize the critical areas identified in each concept with associated risk to the success of the concept. In addition, the proposed methods of solution/verification with approximate development schedules are included.

SURFACE EMPLACEMENT			
Critical Area	**Risk**	**Proposed Method of Solution**	**Development Schedule**
Geotextile Bag Hydrodynamic Test	Low	Full Scale Bag Test and Evaluation	6 - 8 Months
Bag Release Mechanism	Low - Med	Design/Fabricate/Test Full Scale Single Cargo Cell	6 - 8 Months

Table 8.0-1
Surface Emplacement

ROV GLIDER			
Critical Area	**Risk**	**Proposed Method of Solution**	**Development Schedule**
Hydrodynamic/ Control System Simulation: Descent, Leveling Out, Cargo Release and Ascent	High	Dynamic Simulation, Math Modelling or Simulation Based Design Techniques	6 Months
Verification of Hydrodynamic Simulation	Low	Scale Model Hydrodynamic T&E 1/36 Scale in Tank	12 Months
Acoustic Navigation at >6000 m	Med - High	Experiment with unmanned ROV to determine acoustic positioning reliability/accuracy	9
Proof-of-Principle: Technical/Operations	Med - High	Fully Functional 1/10 Scale T&E:	24 Months

Table 8.0-2
ROV Glider

DIRECT DESCENT DISK			
Critical Area	**Risk**	**Proposed Method of Solution**	**Development Schedule**
Hydrodynamic Simulation: Descent, Braking, Cargo Release, and Ascent	Med	Dynamic Simulation, Math Modelling or Simulation Based Design Techniques	6 Months
Verification of Hydrodynamic Simulation	Low	Scale Model Hydrodynamic T&E 1/36 Scale in Tank	12 Months
Proof-of-Principle: Technical/Operations	Med - High	Fully Functional 1/4 - 1/2 Scale T&E:	24 Months

Table 8.0-3
Direct Descent Disk

PIPE RISER			
Critical Area	**Risk**	**Proposed Method of Solution**	**Development Schedule**
Catenary Analysis	Low - Med	Optimization Studies versus Currents, Unit Loading, and Transient Flow Effects	4-6 Months
Manned versus Unmanned Operation	Low - Med	Detailed study of platform subsystem automation feasibility/risks	6 Months
Station Keeping	High	Detailed study to determine feasibility of high reliability dynamically positioned surface platform coupled to a mobile, bottom moored pipe string	6 Months
Interface w/ Transport Ship	Low - Med	Study of existing technology for docking a ship with a floating pumping station	3 Months
Dilution Flow Monitoring/Control	Med	Design/Build/Test a proof-of-principle system at 1/10 scale flow rates	9 Months
Installation of pipe	Med	Study applicability of state-of-the-art offshore pipe installation techniques	3 Months
At-Sea Maintenance	Med	Study maintainability of "permanent" pumping platform at sea	3 Months
Riser Dynamic Response	Med - High	Dynamic Analysis via Computer Simulation	1-2 Months

Table 8.0-4
Pipe Riser

The above tables illustrate that, although each of the concepts are considered to be technically feasible, every concept has a set of unique issues to be resolved prior to development of a production APWI system. Based on the above tables, and consistent with the Reliability Analysis of Section 6.0, the concepts can be ranked in relative order of increasing development risk as follows:

- Surface Emplacement
- Direct Descent Disk
- ROV Glider
- Pipe Riser

The natural conclusion is that Surface Emplacement is the preferred technical concept. It is the least complicated and is readily scalable from existing experiments currently being conducted by the U.S. Army Corps of Engineers. The downside of this approach is that the bags are expected to drift apart as they fall through the water column. During early experimentation to assess environmental impact of APWI, it is envisioned that bag mounds, simulating full scale operation in a localized area, would be required to be monitored over a period of time. In

order to accommodate this experiment, the bags would have to be deposited in a very small area. Surface Emplacement is not conducive to such a very small area experiment.

The next most desirable technical choice is the Direct Descent Disk. The Disk has the feature of depositing groups of bags in a very localized area. Therefore, this concept would be quite appropriate for early experiments. Its increased complexity over Surface Emplacement make it somewhat less desirable as a long term, full scale APWI emplacement system. However, the Direct Descent Disk can also be used as a surface emplacement system. Therefore, it may be desirable to have a dual use system which can carry highly hazardous wastes to the seafloor prior to release and simply release minimally contaminated material from the surface. This approach minimizes the environmental hazard produced by a possible bag rip at the surface during release.

The ROV Glider concept has basically the same attributes as the Direct Descent Disk. The Glider is potentially capable of landing bags in a smaller target area during emplacement, but it also carries the associated liability of increased complexity in the control of a very large submersible, autonomous vessel. Compared to the Direct Descent Disk, its increased emplacement accuracy does not offset the increase in technical risk.

The Pipe Riser concept is primarily an extrapolation of offshore oil technology. However, the number of issues that require extensive extrapolation of state-of-the-art are quite significant. The benefit it provides as an APWI concept is its emplacement accuracy and its inherent ability to cap any waste stream with clean sediment. However, capping may not be an issue when compared to the other concepts since they contain their waste in bags (for some significant period until the bag fabric degrades or is penetrated). Also, from a testing perspective, this concept is the most difficult to effectively test in scale form. Most issues can only be modelled via computer simulation. At that point, full scale testing is required. For example, there is no good way to test, in reduced scale, the assembly of four 1.37 m (54 in) diameter pipes, in excess of 6100 m (20,000 ft) long in the open ocean. For the above reasons, the Pipe Riser concept appears to be the least technically desirable APWI emplacement option.

It is worth noting that the top three concepts employ a bagged-waste approach to achieve isolation from the water column. This conclusion alone has a significant impact on environmental aspects of deep ocean isolation. Assuming the bags stay intact on the seafloor, dispersion of the contained material is no longer an issue. Other factors, such as chemical and biological activity within the bags are now of significant interest. Also, bag mounds will create a local environment with topographical diversity. The effect of this diversity on attracting deep sea organisms is an issue that has been raised by some scientists associated with this study. These issues and others are addressed in the Environmental Report (Valent et al. 1995) of this APWI study.

As identified in the system requirements, current top level environmental regulations would require modification to allow for the Abyssal Plains Waste Isolation of dredged material, sewage sludge, and municipal incinerator fly ash. Table 8.0-5 includes a listing of these very top level federal and international regulations that place constraints on this project.

Regulation	Impact on APWI Concept	Importance
Ocean Dumping Ban Act (1988 Amendment to MPRSA)	Made it unlawful to dispose of sewage sludge in the ocean.	Unless it is modified, sewage sludge can not be legally isolated on the abyssal seafloor.
Resource Conservation Recovery Act (RCRA)	Dictates testing, handling, transport and disposal practices for hazardous waste.	By law, fly ash must be tested to determine if it contains hazardous materials. If found to be hazardous, RCRA sets handling, packaging, transportation and disposal practices to be followed.
London Dumping Convention, The International Convention on the Prevention of Pollution from Ships (MARPOL), and Marine Protection, Resources, and Sanctuaries Act (MPRSA)	Unlawful to dump persistent synthetics in the ocean.	May restrict the use of synthetic geotextile containers.
London Dumping Convention	Prohibited/Restricted Dumping of certain substances regarding ocean disposal.	Testing of fly ash to determine if it is hazardous may reveal the presence of one or more of these prohibited/restricted substances.

Table 8.0-5
Top Level Environmental Regulations and Constraints on APWI

9.0 RECOMMENDATIONS

The following recommendations are made:

- Further testing of geotextile bags proposed for containment of dredge material, sewage sludge, and municipal incinerator fly ash should be conducted. Three technical issues are bag hydrodynamic characterization during free-fall, cargo cell release mechanism design to minimize stress on bags during release, and bag rupture resistance upon landing on the seafloor.

- Design and development of a scaled Direct Descent Disk for emplacement of relatively large quantities of waste-filled bags in mounds should be undertaken for environmental assessment of deep ocean isolation.

- A customized, full-scale Surface Emplacement system would not be warranted until the results from the above two recommendations are available.

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GLOSSARY

A_o - Operational Availability

ARTICOUPLE - Proprietary variant of a semi-rigid structural linkage used for barge-tug connection

ARTUBAR - Proprietary variant of a semi-rigid structural linkage used for barge-tug connection

ABS - American Bureau of Shipping

APWI - Abyssal Plains Waste Isolation Project

BHP - Horse Power

BM - Distance between metacenter and the center of buoyancy

CFR - Code of Federal Regulations

COE - U.S. Army Corps of Engineers

CSSL-IV - Combined System Simulation Language IV

DWT - Dead Weight Tonnage

FLEXOR - Proprietary variant of a semi-rigid structural linkage used for barge-tug connection

FMECA - Failure Modes, Effects, and Criticality Analysis

FTA - Fault Tree Analysis

GPS - Global Positioning System

HDPE - High Density Polyethylene

HEA - Hydraulically Embedded Anchor

IRAD - Internal Research and Development

ITB - Integrated Tug/Barge

LSHT - Low Speed High Torque

MARPOL - International Convention of Prevention of Pollution from Ships

MCR - Maximum Continuous Rating

MPRSA - Marine Protection, Research and Sanctuaries Act of 1972

MTBF - Mean Time Between Failure

MTTR - Mean Time To Repair

NRL - Naval Research Laboratory

OA - Overall Length

OTECH - Oceaneering Technologies, Inc.

PFTE - Polytetra-fluoroethylene (coating material)

RCRA - Resource Conservation and Recovery Act of 1976

RESCO - Refuse Energy Systems Company (Waste-to-Energy Incinerator)

ROV - Remotely Operated Vehicle

Rulon - Trade name for a low friction, high load-bearing plastic

Sea-Link - Proprietary variant of a semi-rigid structural linkage used for barge-tug in which the tug does not touch the barge

Sealol - Trade name for a shaft seal

SERDP - Strategic Environmental Research and Development Program

SOLAS - Safety of Life at Sea

TBD - To Be Decided

TFE - Tetra-fluoroethylene (coating material)

USBL - Ultra Short Baseline

VCG - Vertical Center of Gravity

WL - Water Line (Length of a ship along the water line)

CONVERSION TABLE

TO CONVERT FROM	TO	MULTIPLY BY
foot (ft)	meter (m)	0.3048
foot, cubic (ft^3)	meter, cubic (m^3)	0.02832
foot per second (ft/s)	meter per second (m/s)	0.3048
foot per second squared (ft/s^2)	meter per second squared (m/s^2)	0.3048
gallon, U.S. liquid (gal)	liter (l)	3.785
horsepower (550 ft- lbf/s)	watt (W)	745.7
inch (in)	meter (m)	0.0254
knot	meter per second (m/s)	0.5144
mile, nautical (nmi)	meter (m)	1852
pound mass (lbm)	kilogram (kg)	0.4536
pound force (lbf)	newton (N)	4.448
pound force per square inch (lbf/in^2)	kilopascal, or kilonewton per square meter (kPa)	6.895
pound force per square foot (lbf/ft^2)	pascal, or newton per square meter (Pa)	47.88
pound mass per cubic foot (lbm/ft^3)	kilograms per cubic meter (kg/m^3)	16.02
ton, long, 2240 lbm	megagrams (Mg)	1.016
ton, metric	megagrams (Mg)	1.000
ton, short, 2000 lbm	megagrams (Mg)	0.9072
yard (yd)	meter (m)	0.9144
yard, cubic (yd^3)	meter, cubic (m^3)	0.7646

Appendix A

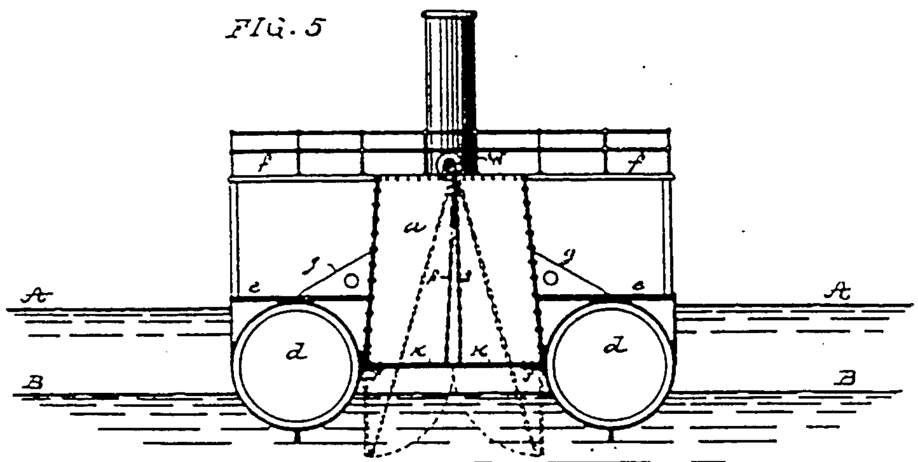
Pictorial and Summary for 30 Patent Concepts

Appendix A

(1) Patent #542,408, July 9, 1895 by D. Delehanty "Dumping Scow"

- o For garbage or refuse, self-powered barge/ pontoon-supported/ compartmented, with bottom trap doors.
- o Vessel rises out of the water upon release of the refuse freeing the compartment receptacles of floating mass.

FIG. 5



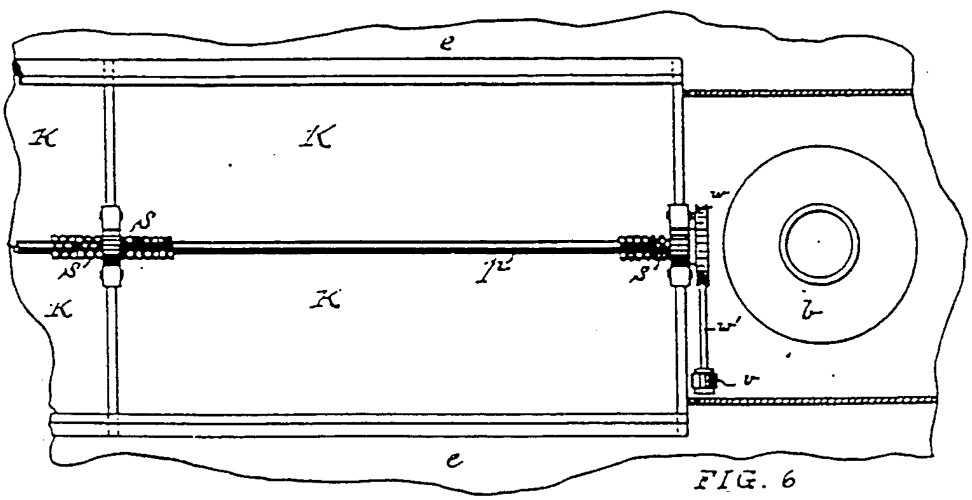
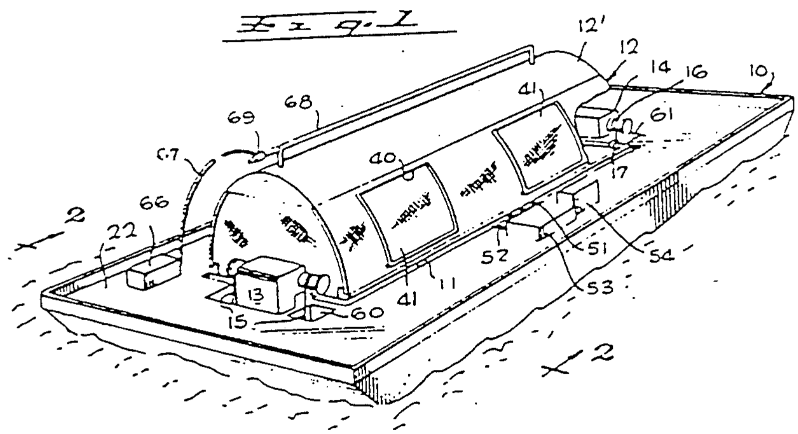
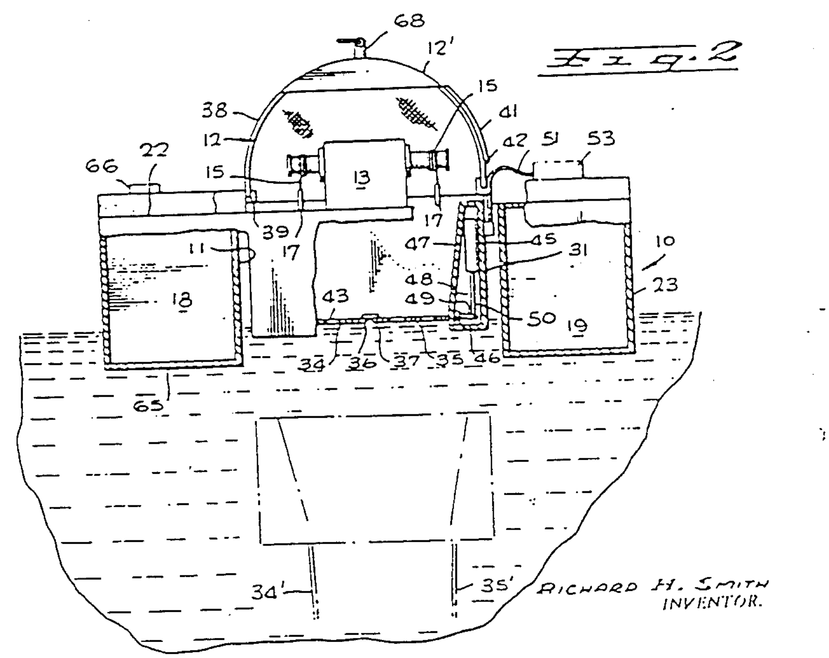


FIG. 6

(2) Patent #3,456,824, July 22, 1969, by R.H. Smith "Deep Sea Refuse Disposal"

- For garbage or refuse, barge with windlass lowered container having trap doors, and capable or release of the garbage or refuse at greater than the material's critical depth, such that the material looses all positive buoyancy.
- Eliminates disposable containers

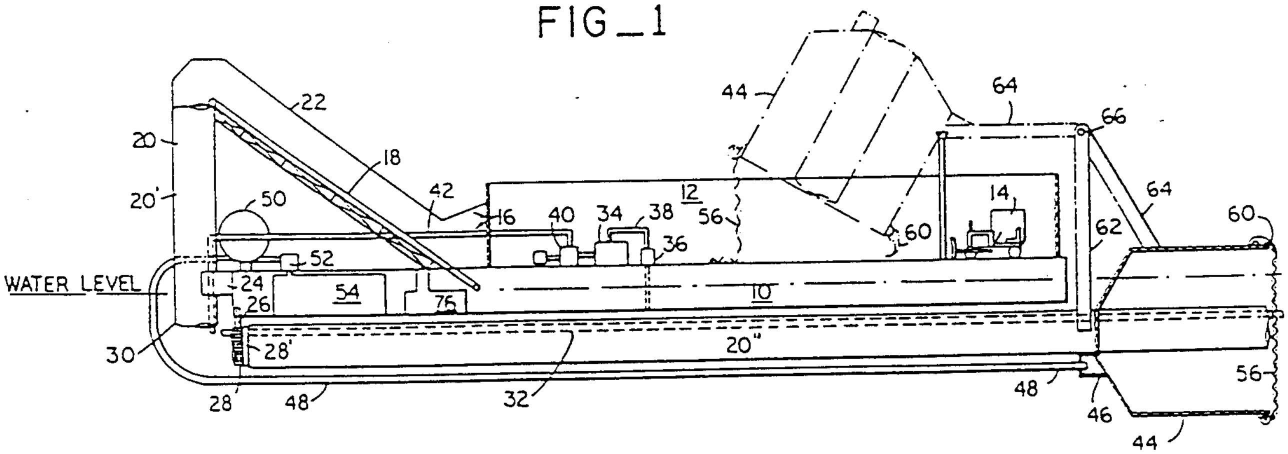




(3) Patent #3,595,161, July 27, 1971, by W.A. Webb "Method & Apparatus for Refuse Disposal"

- o For solid waste material or refuse, fixed site disposal barge with large diameter telescoping pipe, approximately 50ft above the surface to 300 ft. below the surface.
- o The waste material is compressed by sea pressure.
- o Lower Terminus has a trap to collect any residual materials that can float after being compressed.

FIG_1



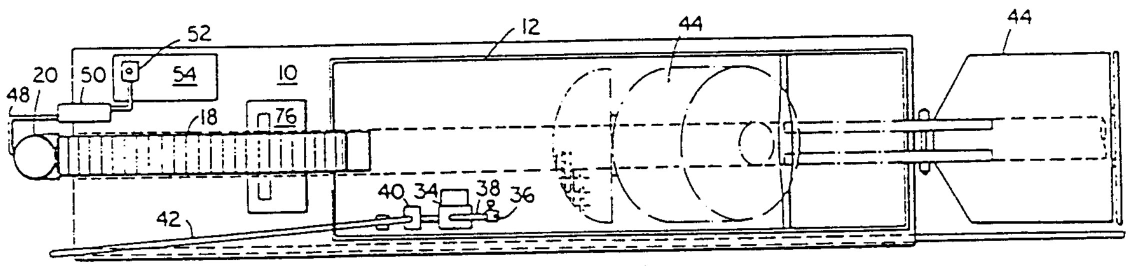
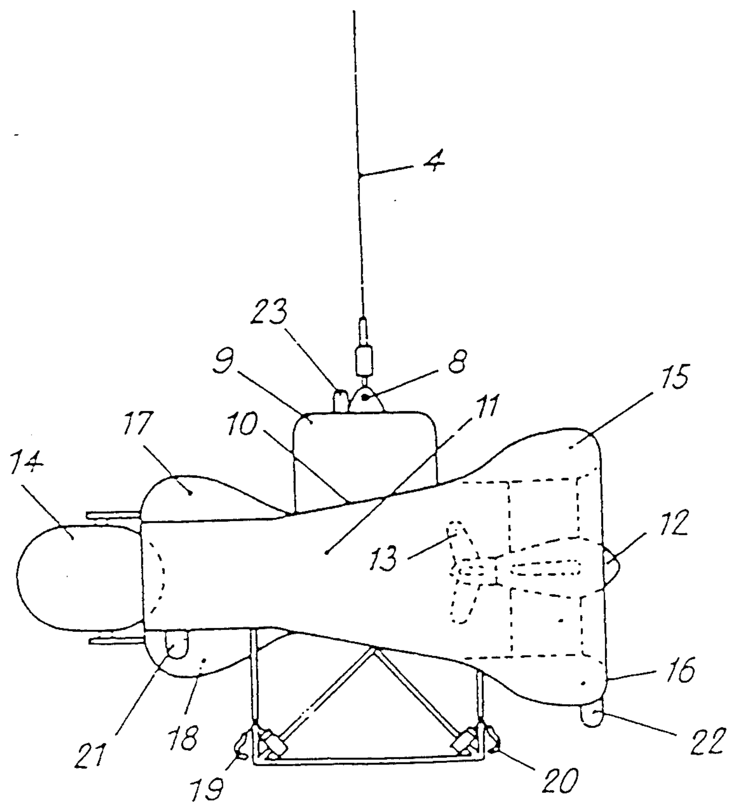


FIG_2

(4) Patent #3,633,529, 11 Jan., 1972, by F.M. Sereano "Mobile Carrying system for Depositing Loads on Ocean Bottom"

- o Self-powered/ tethered submarine delivery system for depositing "several tons" at precise locations on the ocean bottom.
- o Intended for supporting undersea drilling operations.
- o Eliminates need for a heavy duty tether by the use or the submarine buoyancy.



(5) Patent #4,305,679, 21 Dec., 1979, by F.L. Goldsberry "Submersible Barge Retrievable Storage & Permanent Disposal System for Radioactive Waste"

- o Triple-redundancy concrete cell containment system, sealed, actively vented when on the surface, passive convection when on the seabed.
- o Employs a "submarine control device" for both lowering and retrieving the barge (no specific details provided).

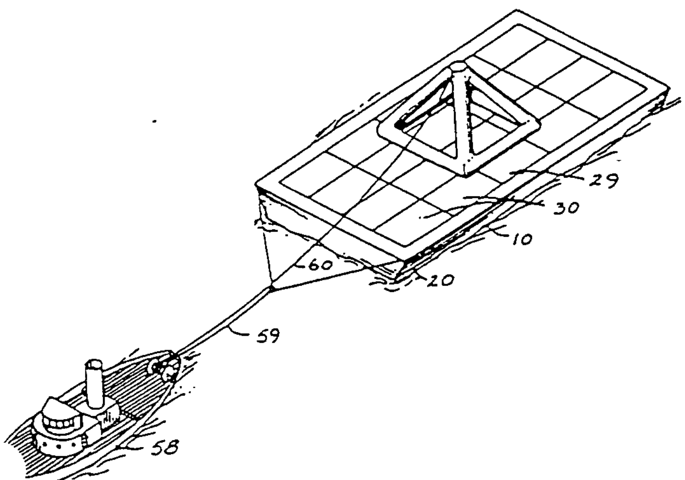


FIG 1

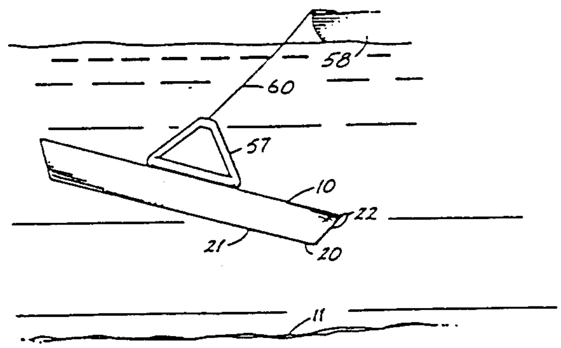


FIG 3

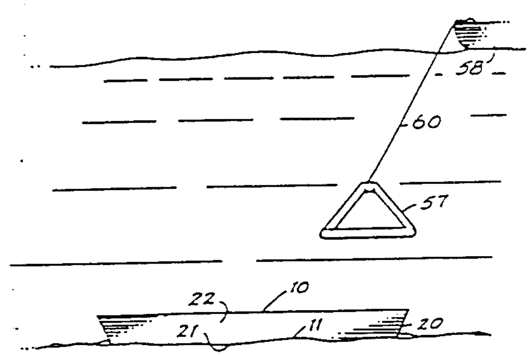


FIG 4

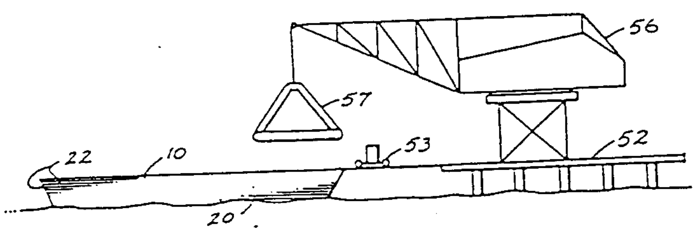


FIG 2

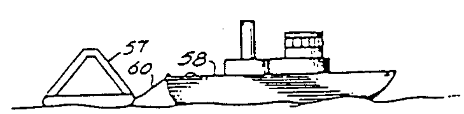
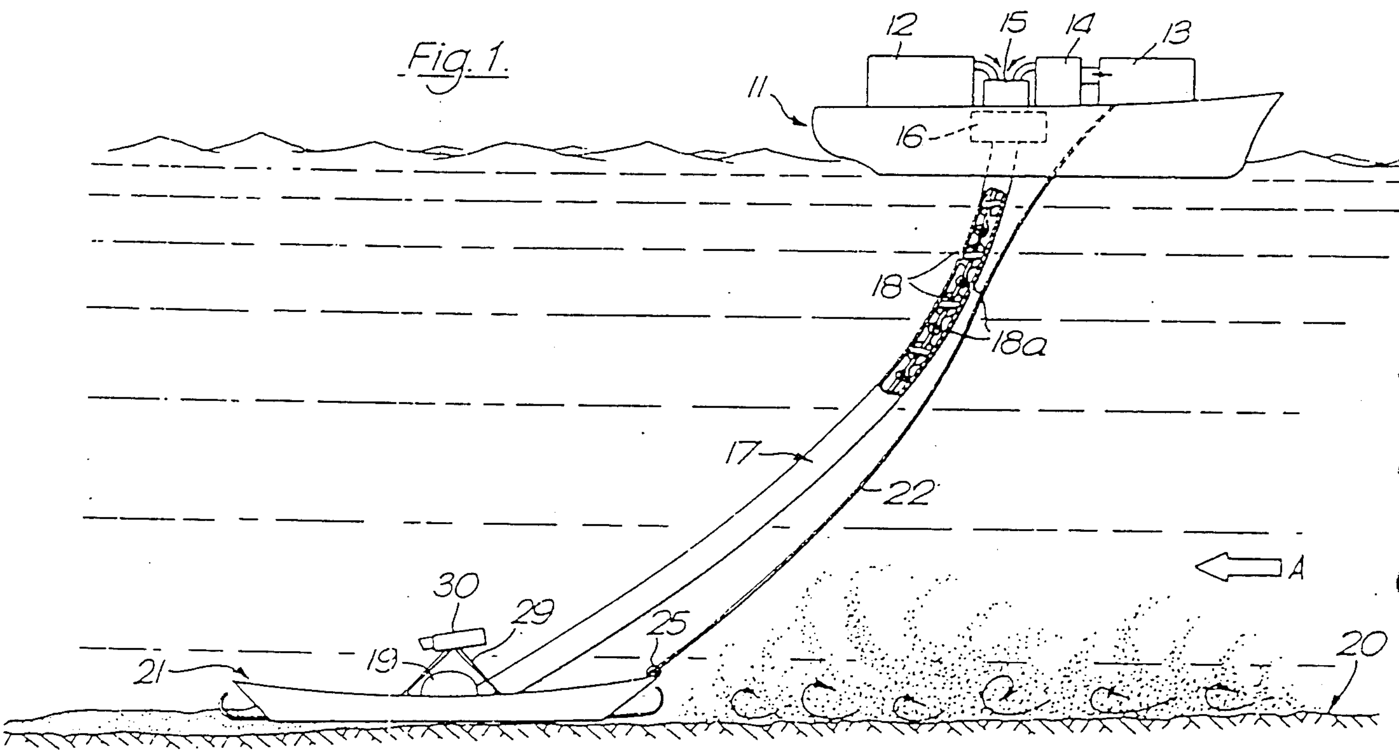


FIG 5

(6) Patent # 4,352,590, 11 Dec., 1980, by Parker, et al. "Stabilization of Erodible Marine or Fluviatile Sediments"

- o Employs a non-setting paste-like slurry (mud or clay in a gravel framework) to stabilize erodible marine sediments, mixed on board, and pumped through up to 6ea. 11.8 diameter lines having a chain of screw links.
  - ■ Provides up to 6490 cubic meters delivery or allows plough advance at rate or approximately 40 FPM, assuming 10 cubic meters deposited per meter pipe length by 1 meter in diameter.
  - ■ Wedge or cover material 1 meter deep X 10 pipe diameters.
- o Uses a deposition head mounted onto a seabed plough, which distribute the stabilizing slurry over the submarine structures such as pipelines and oil drilling rig legs.
- o Includes a seabed/pipeline TV monitor to facilitate tracking.

Fig. 1.



(7) Patent #4,357,764, 9 Nov., 1982, by Lemercier et al. "Submarine Vehicle for Dredging and Raising Minerals on the Seabed at Great Depths"

- o A submarine vehicle capable or raising approximately 30% or it's mass, of 800T displacement, 12m wide, 30m long X 7.5m height.
  - ■ Initially neutrally buoyant, with "sterile material" which is replaced with the dredged material.
  - ■ Acts as a glider for both descent and ascent.
- o The load-bearing structure acts as the buoyancy element.

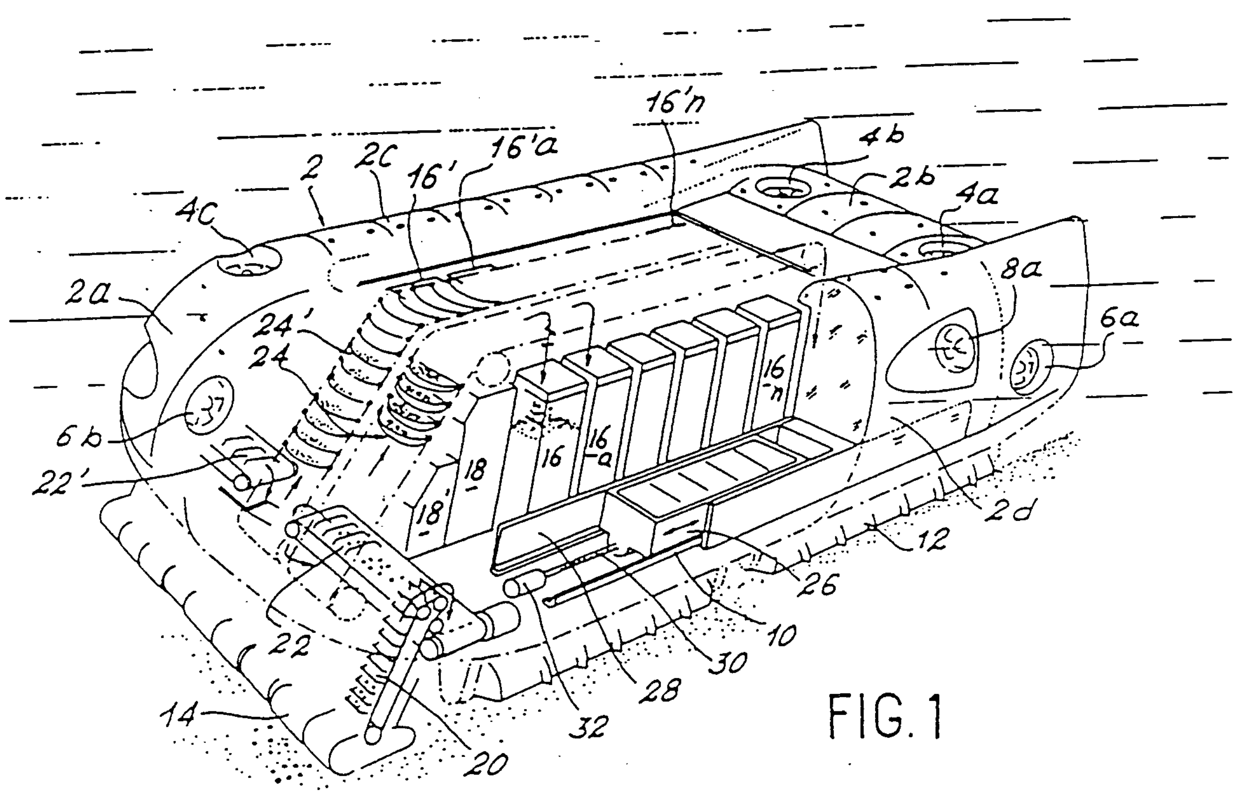


FIG. 1

(8) Patent # 4,400,115, 23 Aug., 1983, by Biancale et al. "Method for Depositing Material on the Ocean Bed and Apparatus for Performing the Same"

- o Uses as autonomous vehicle with hopper to track an undersea pipeline or cable and a vertical riser not mechanically connected to the hopper--but with the lower terminus actively powered and dynamically positioned to the hopper track.
- o Discussed method of operation in waters of > 100m depth, with surface ship dynamic positioning to within approximately 1% of the depth.

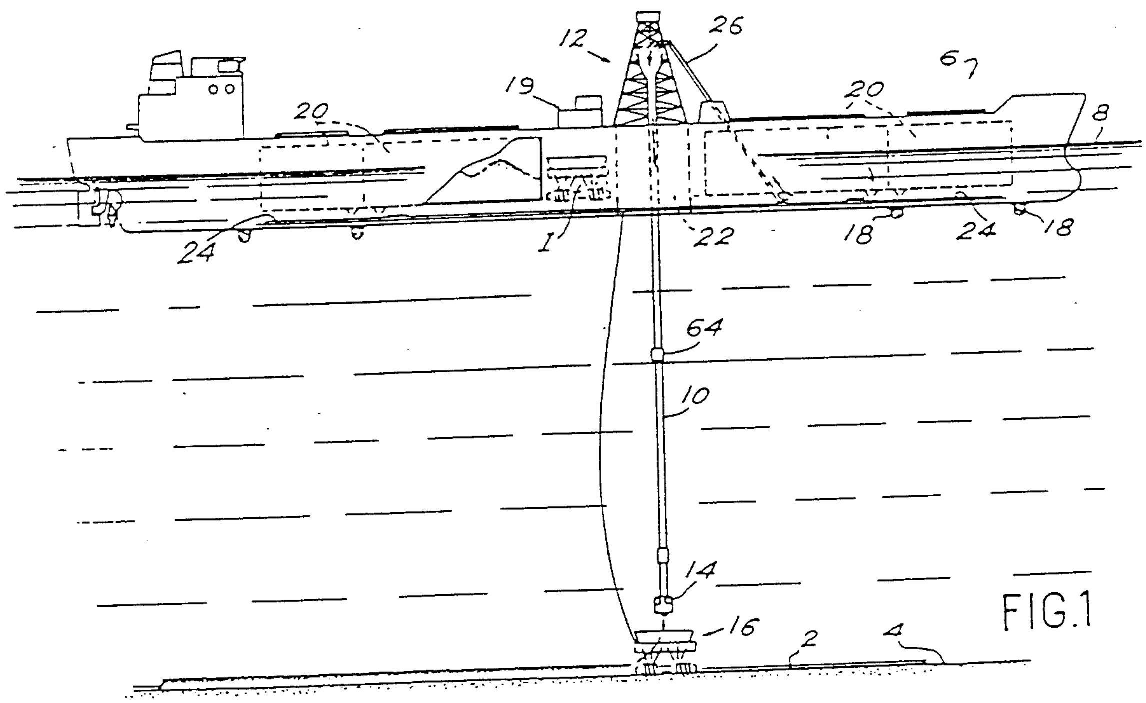


FIG.1

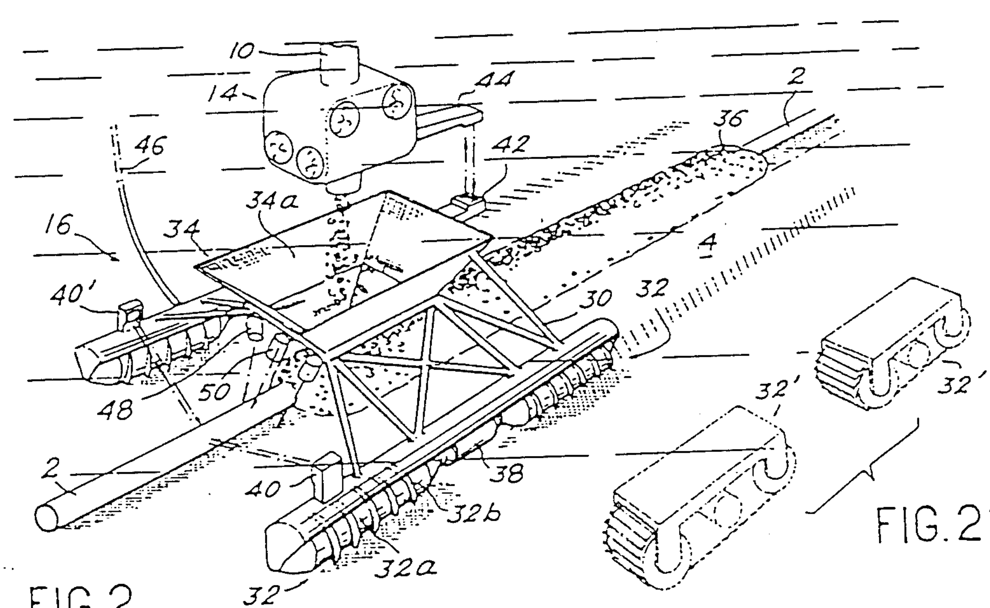
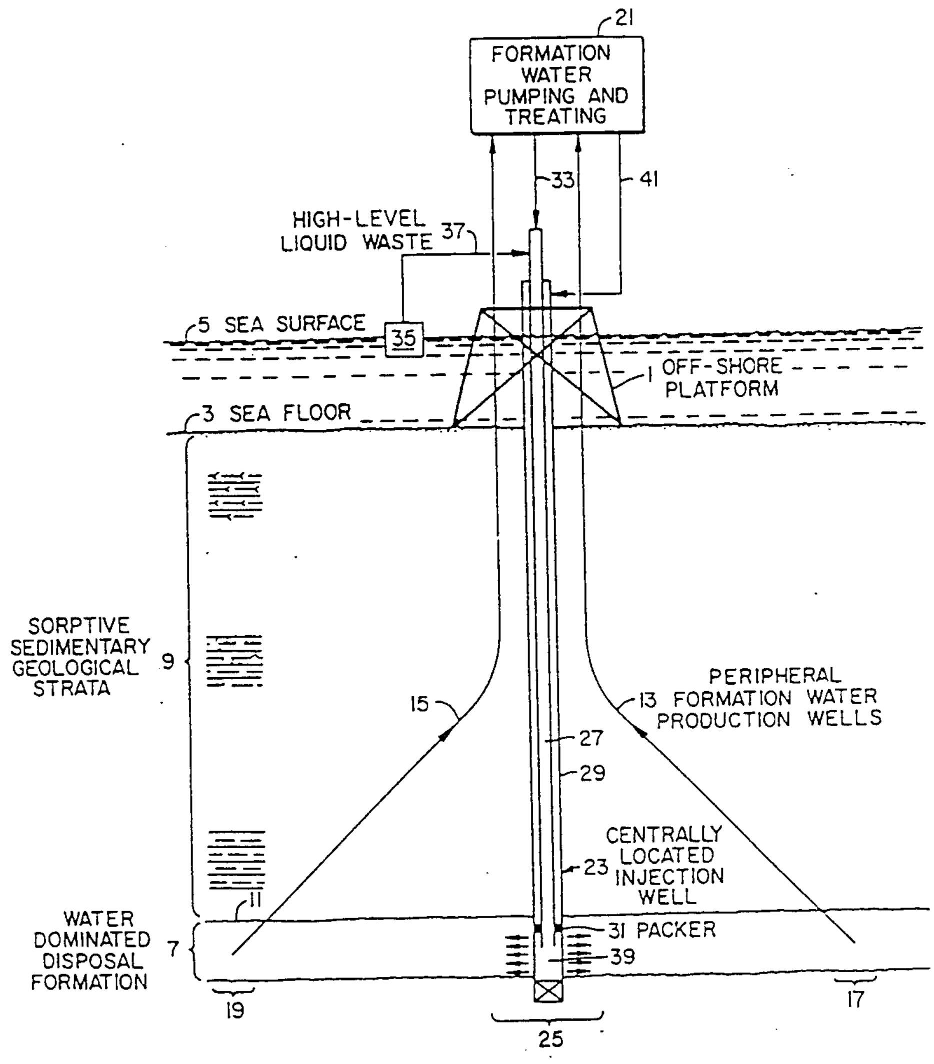


FIG.2 FIG.2'

(9) Patent #4,400,314, 23 Aug., 1983, by Ellis et al. "Method for the Ultimate Disposal of High Level Radioactive Waste"

- Employs aqueous dilution of high level liquid waste (HLLW) with water produced from a deep, offshore, geological formation, and confinement of the dilute waste in a similar formation (subsea location).
- Must be >1000m below sea floor, with impermeable strata located above a highly sorptive sedimentary deposit, dominated petroleum reservoir.
- Water drawn peripherally from the central injection point to enhance uniform radial dispersion of the dilute HLLW.



(10) Patent #4,452,478, 5 June, 1984 by Dulaney "Nuclear Waste Storage Process and System"

- o Employs a system to both transport and deposit nuclear waste products in CRES canisters 2" smaller in diameter than the abandoned or dry oil well hole at depths of 10,000 to 15,000 feet.
- o Recommends "pressure compensation" by filling the voids within the canister with molten glass, or similar to minimize potential for structural failure under induced column loading.

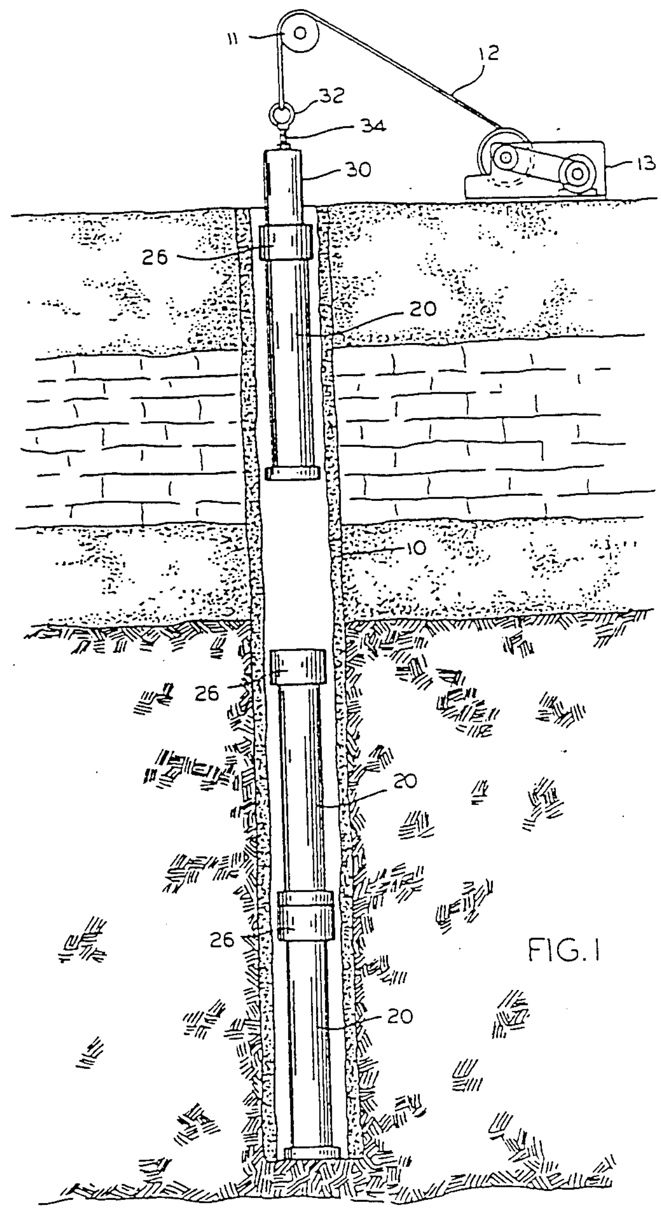
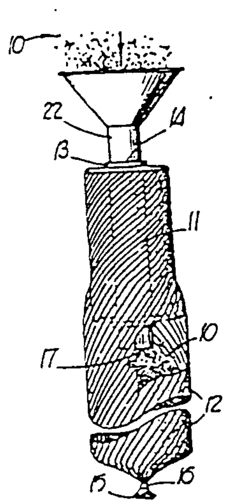


FIG. 1

(11) Patent #4,518,507, 21 May, 1985, by Conner "Method for Chemically Solidifying and Encapsulating Hazardous Wastes in One Continuous Operation"

- o Employs an approximately 1 ft. diameter polyethylene membrane to form "sausage link" increments or solidified sewage sludge or similar liquid or semi-liquid waste.
- o Uses a water reactive solidification agent, a dry water absorbent material and a powdered alkali metal silicate to convert the admixture into a chemically and physically stable end product containing virtually no water.
- o Permits the encapsulated waste to harden in-situ, setting into a sedentary mass, and prepared for ultimate disposal in landfills, ocean relocation sites and the like.



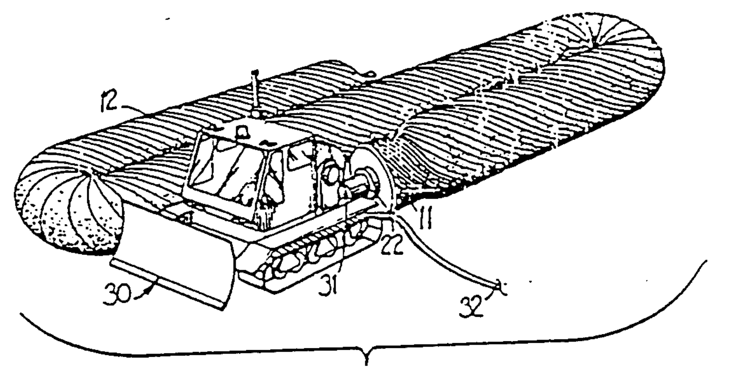


FIG 5

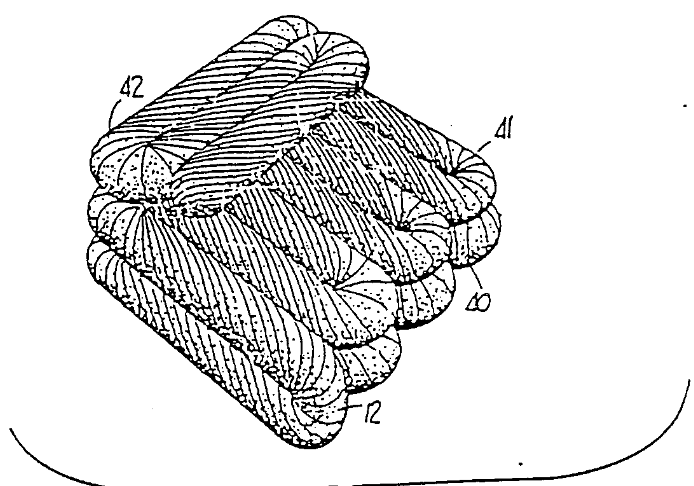


FIG 6

(12) Patent #4,525,100, 25 June, 1985, by Zawadzki, Jr., et al. "Transportation and Disposal of Waste Materials"

- o Employs a temporarily shape-competent (box) but excess moisture-vulnerable type container with flexible fluid filled impervious liners.
- o Takes advantage of the slump down due to "shake-down" transport from the source to storage facility, caused by liberation of entrained air or absorbed air, to affect similar action between contiguous containers to spread against each other and close any previously existing spaces therebetween.

Fig. 1.

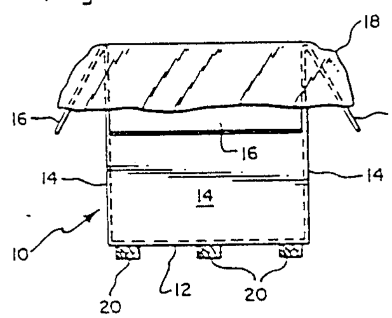


Fig. 2.

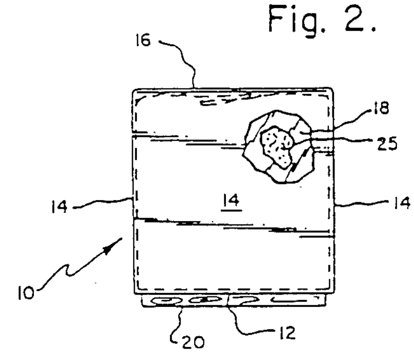


Fig. 3.

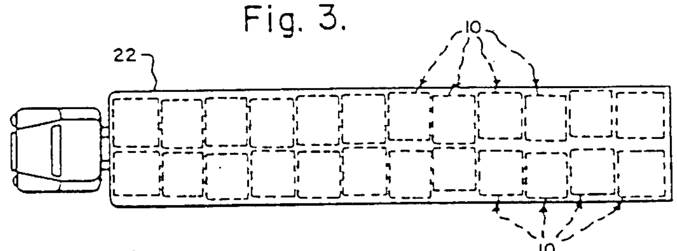


Fig. 4.
THE INVENTION

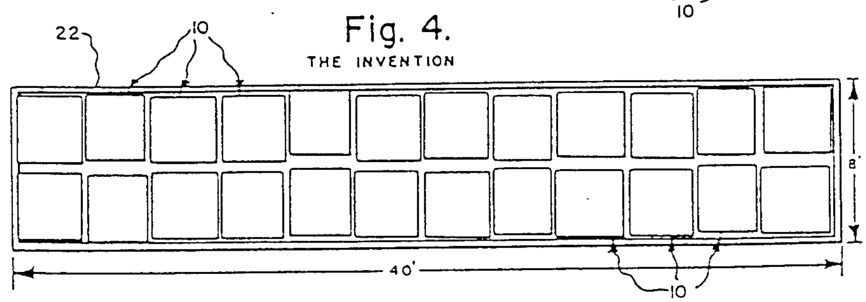
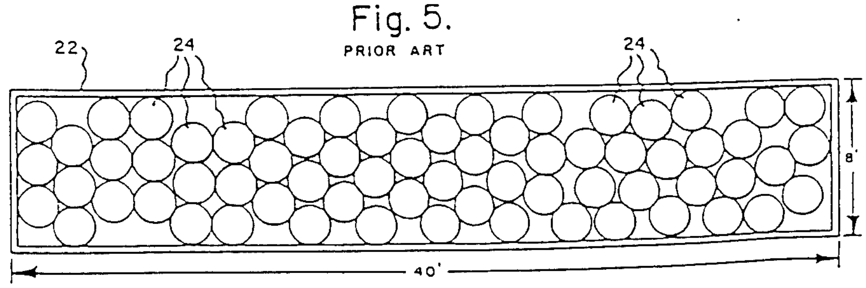


Fig. 5.
PRIOR ART



(13) Patent #4,815,894, 28 Mar., 1989, by A.G. Copson "Construction and Use of Subsea Bore Holes"

- Employed for the safe emplacement and disposal of a large waste object (shielded reactor core) beneath the seabed in a large diameter bore hole from 10 to 50 meters across.
- Outer peripheral array of bore holes about the circumference have material supplied to stabilize the surrounding geologic formations and permits the realization of the desirable "cased"bore hole of large diameter and similar to features present in smaller (e.g. 3m diameter) producing oil and gas from subsea bed reservoirs.

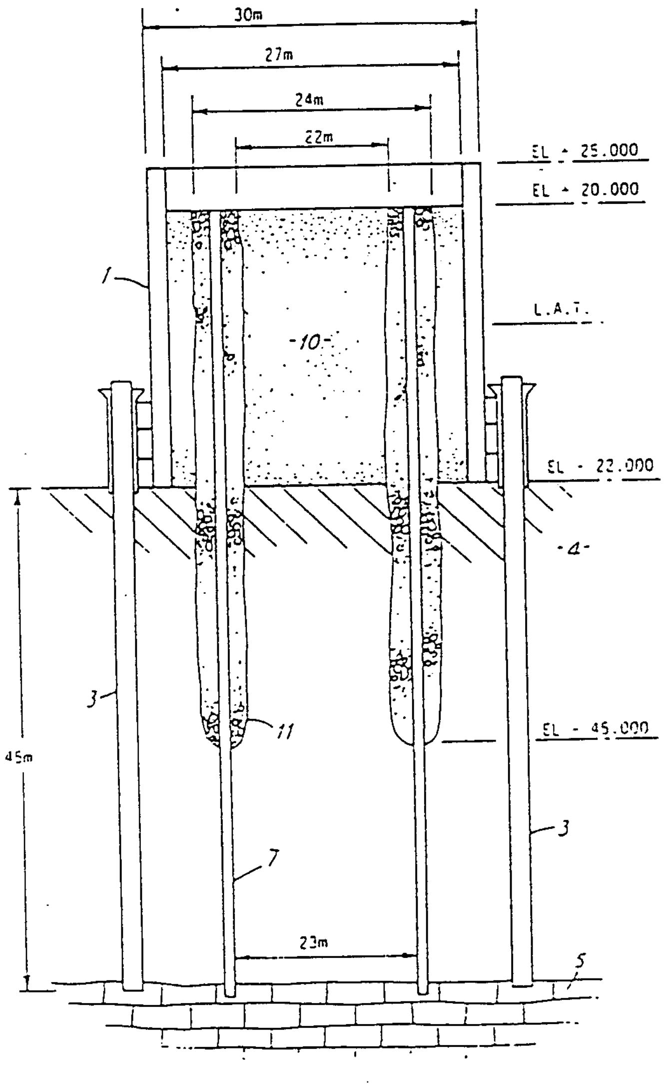


FIG.3

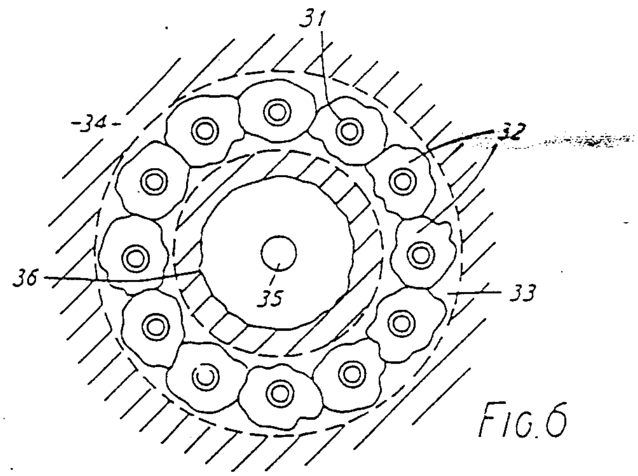


FIG.6

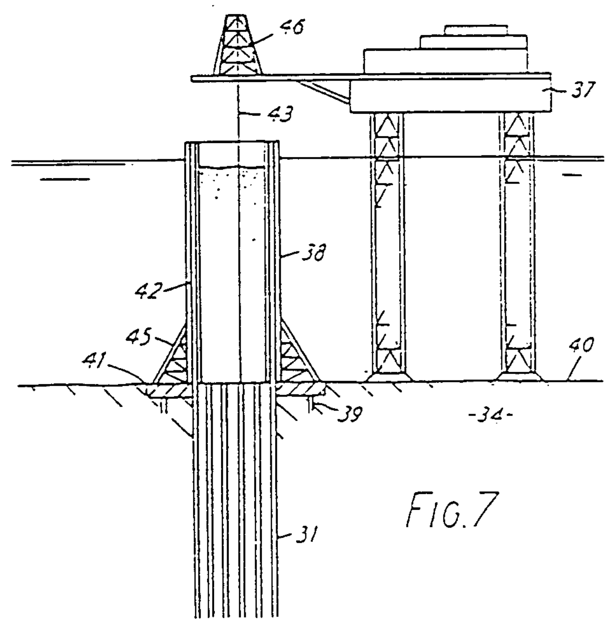


FIG.7

(14) Patent #4,829,923, 16 May, 1989, by A.G. Copson "Sewage Disposal"

- o Treated sludge, at 5-10% solids by weight, transported to a deepwater site and discharged through .45-.5 m pipelines for unassisted flow of approximately 1000T/Hr, to sea floor depth of up to 7000 m.
- o Either flexible polypropylene of continuous length up to 7000 m, mounted on a reel approx. 60 ft. barrel diameter X 7 m width, and/or consist of segments approximately 150 ft long. A steel piping riser approach is also discussed and alludes the need for buoyant collars. Either of the approaches requires that the piping assemblies by deployed once the transport vehicle (approx 100,000 DWT) arrives on site.
- o A 40T drop weight is employed at the lower terminus to overcome the effects of ocean currents, including a flow assist pump and a swivel elbow to use directed thrust of the sewage flow to enable some steerable control feature.

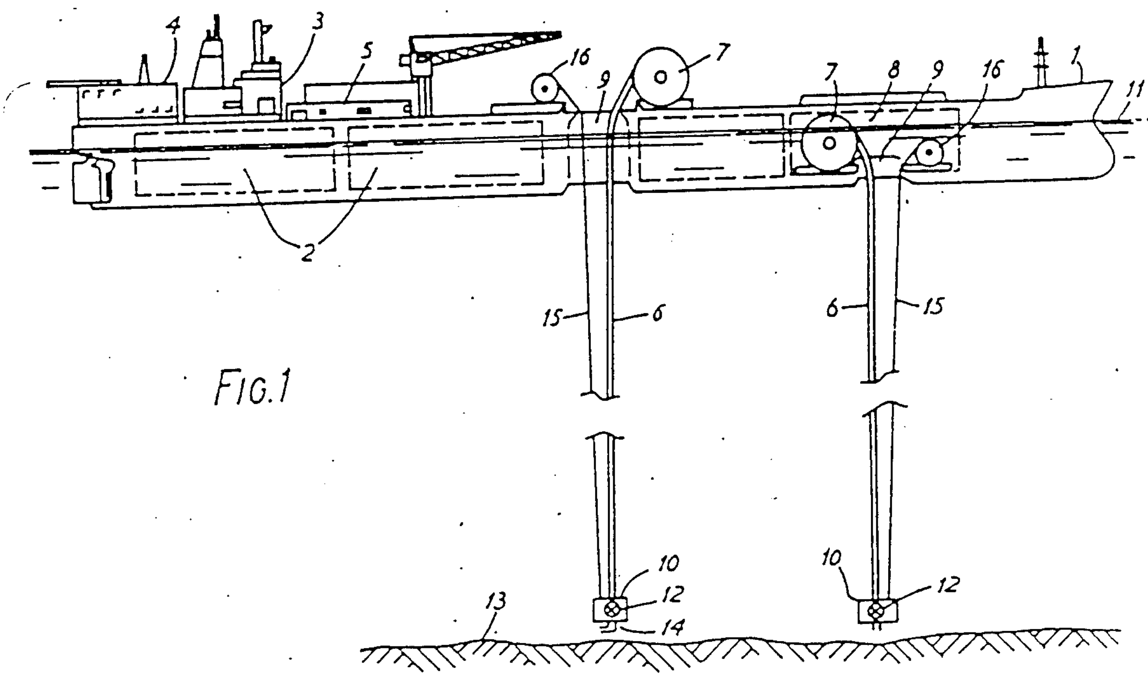
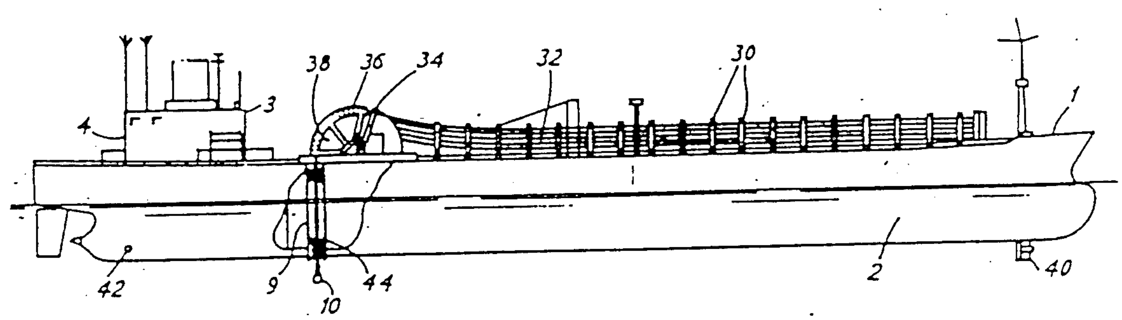


FIG.1



(15) Patent #4,863,638, 5 Sept, 1989, by Harper, III "Process for Hazardous Waste Containment"

- o Describes a process for hazardous waste containment, using successive entombment features:
  - ■ Metal cylindrical drums, lead-lined if low level radioactive waste, banded together with steel straps in groupings of two to eight, entombed with a plastic casing to prevent leakage.
  - ■ Drums encoded/marked to identify contents.
  - ■ Seamless clear plastic casing applied via a steam heated molding process, at least 8 inches thicker than the outer boundary of the containers.
  - ■ Pallet or casing support means provided to facilitate handling and ensure stability, may be biodegradable in cases or underwater placement.
  - ■ Entombed waste can be used as a "building block" for sea walls; minimizing beach erosion; as support platform for objects placed in water; etc.

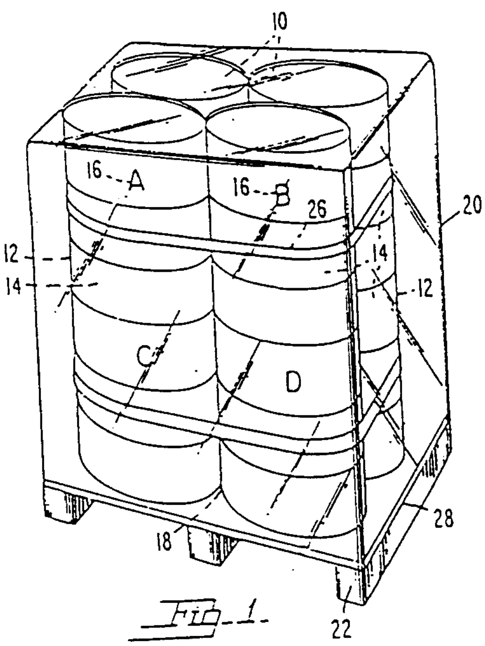


Fig-1-

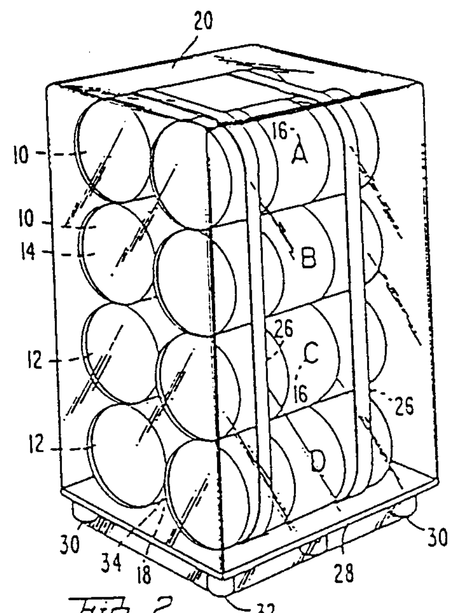


Fig-2-

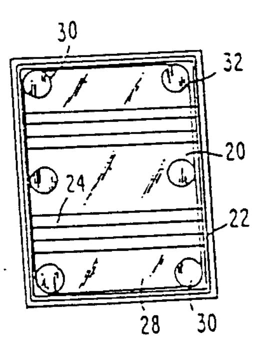
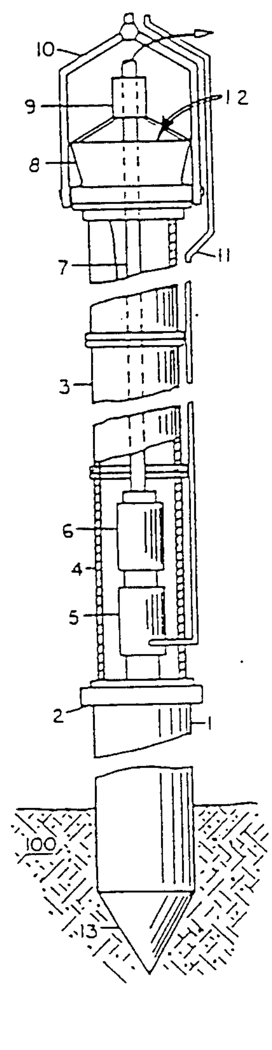


Fig-3-

(16) Patent #4,877,353, 31 Oct., 1989, by Wisotsky, Sr. "Waste Pile"

- o Describes the apparatus and methodology for embedding hazardous waste material deeply within a stable geological formation under deep sea beds.
- o The hazardous material is placed in containers and the containers are placed in hollow piles.
- o The piles are moved to an offshore location and driven into the seabed.
- o The document presents outstanding technical support data and discussion re breadth/scope of the required technologies and environmental issues!



(17) Patent #4,878,446, 7 Nov., 1989, by J. Vermeulen "Method for the Forming and the Deposition in a Selected Place of a Bulk"

- Employs an articulated tank/receptacle with insertable/disposable liner (closable bag) for bulk containment.
- The tank may be opened on the surface or lowered to the desired release depth through several means (cables/straps)
- Intended for loose or lightly cohesive material such as sand or other ground material, for use as the core or vase or a dam, quay, bank reinforcement, a jetty or a breakwater or for filling holes or trenches in the bed or a waterway.

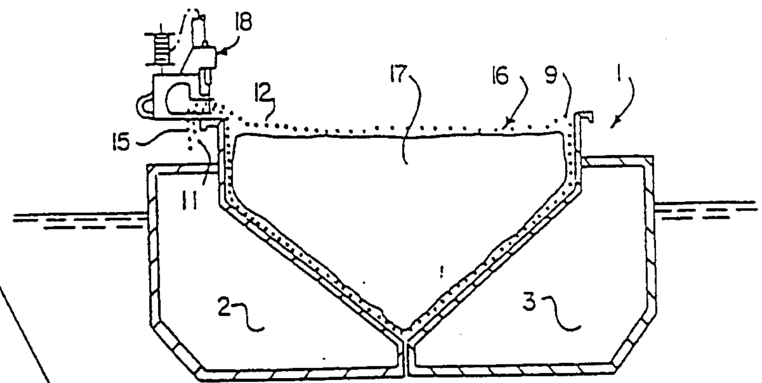


FIG. 4

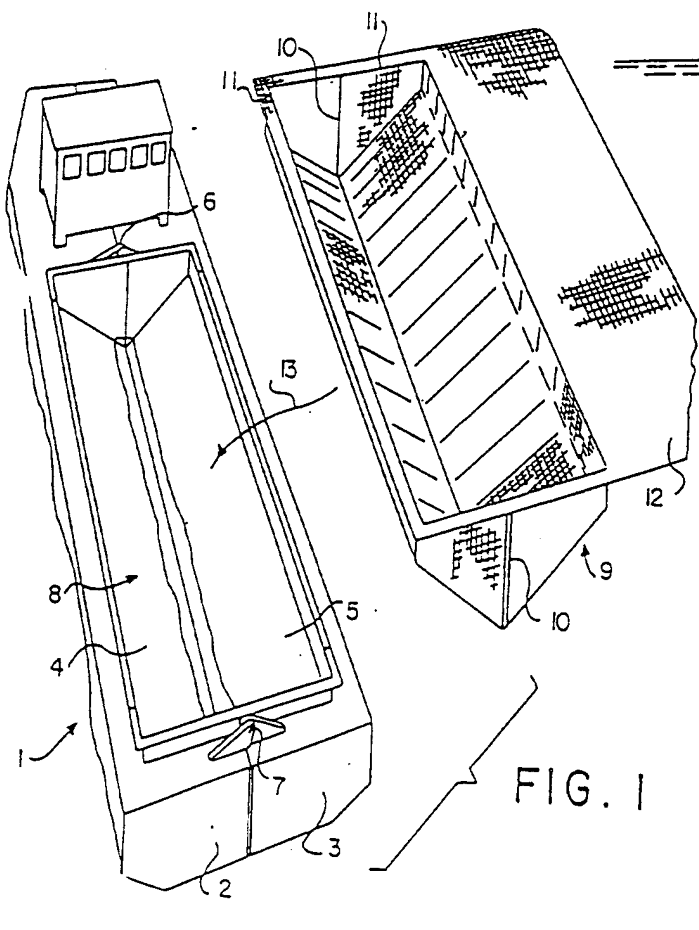
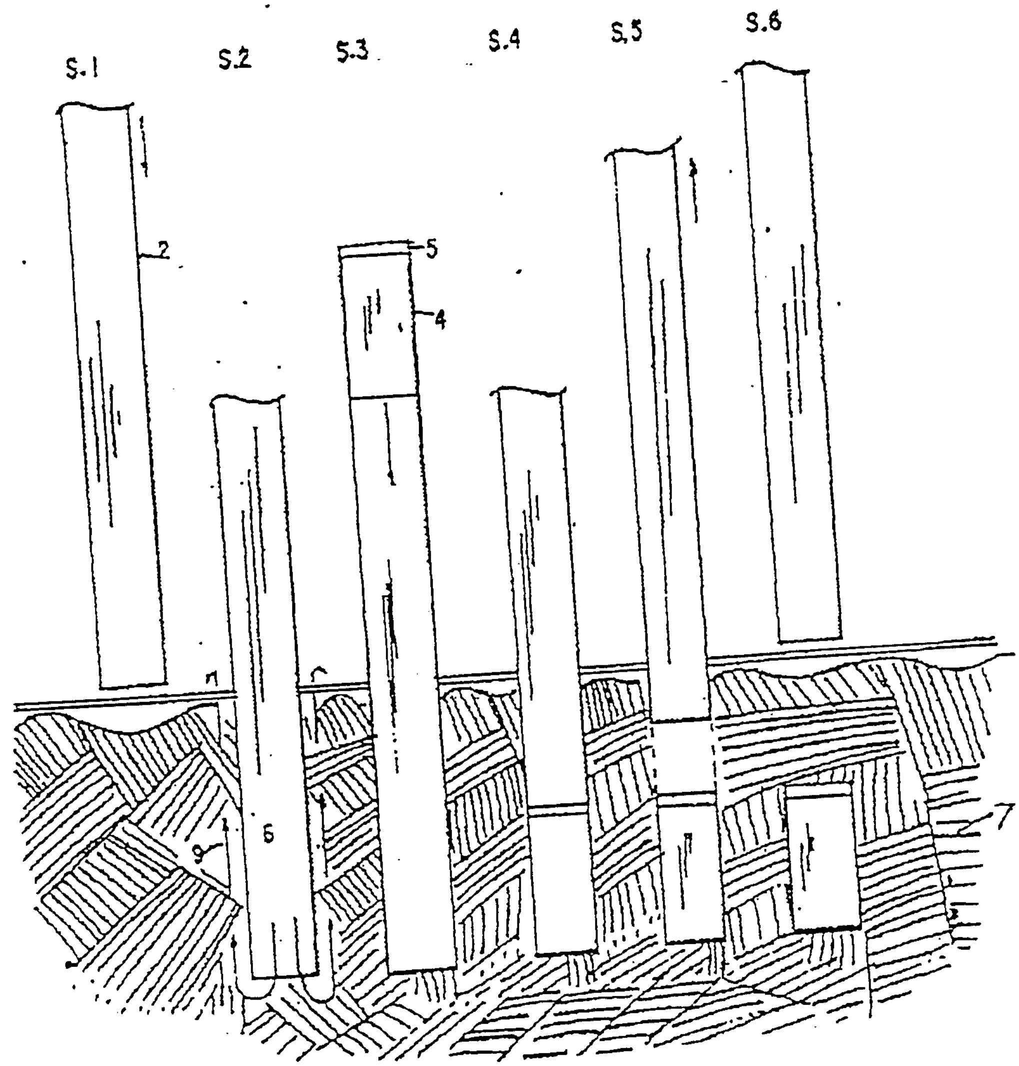


FIG. 1

(18) Patent #4,973,194, 27 Nov., 1989, by M.A. Peterson "Method for Burial and Isolation of Waste Sludge"

- Intended for waste sewage sludge, waste soil, biological wastes, industrial wastes, macerated garbage, mine tailings, incineration ash, dredged material, etc, by placement into relatively large diameter holes in stable undersea geological formations.
  - Preferred sites are the continental margins, where sediments are thick and rapidly accumulating, and the site is not susceptible to geological slumping.
  - Hole depth preferably 100 meters, with "thick paste" inserted into the base of the hose, with density greater than the material of the geologic formation.
  - Hole is filled by the adjacent formation material slumping into the void volume above the waste deposit.
- Note: Dr. M.A. Peterson is Director of the Ocean Policy Institute! Patent assigned to the US Govt as represented by the Secretary of Commerce.



(19) Patent #5,022,788, 11 June, 1991, by J.R. Baird "Subductive Waste Disposal Method"

- o Describes a method for the disposal of nuclear and toxic waste into waste repositories located within a subtending tectonic plate adjacent or near as possible to a subduction zone.
- o The waste material is transferred through access tunnels constructed into these locations
- o This is an excellent writeup!

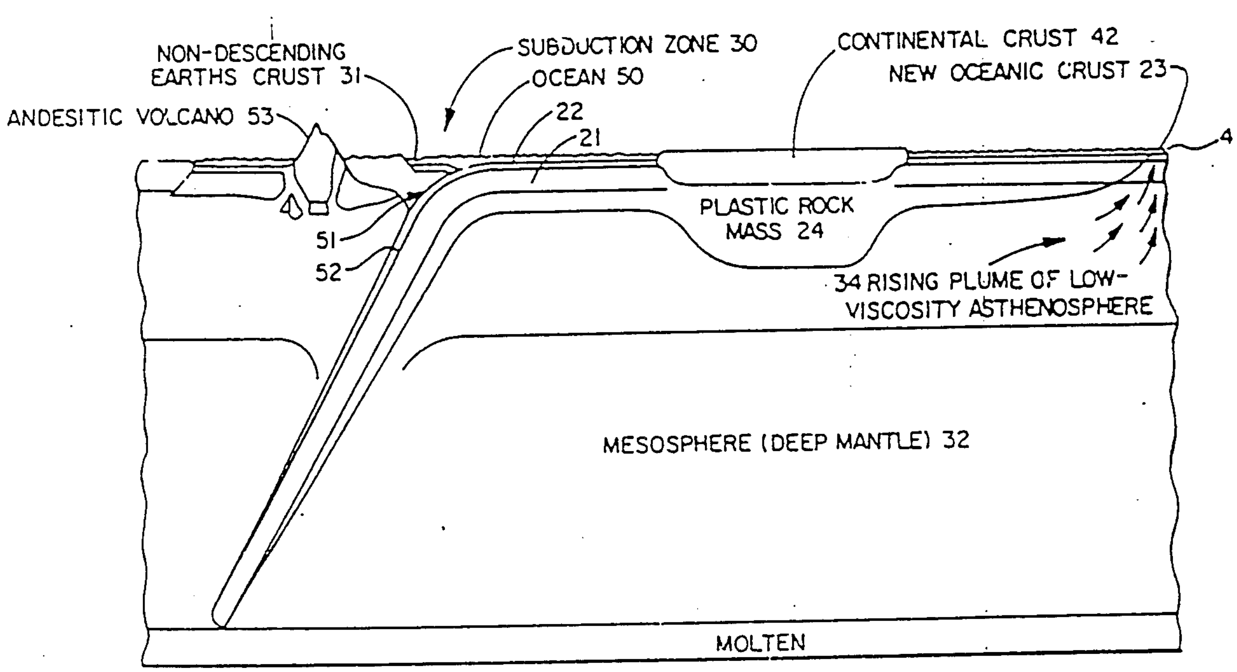
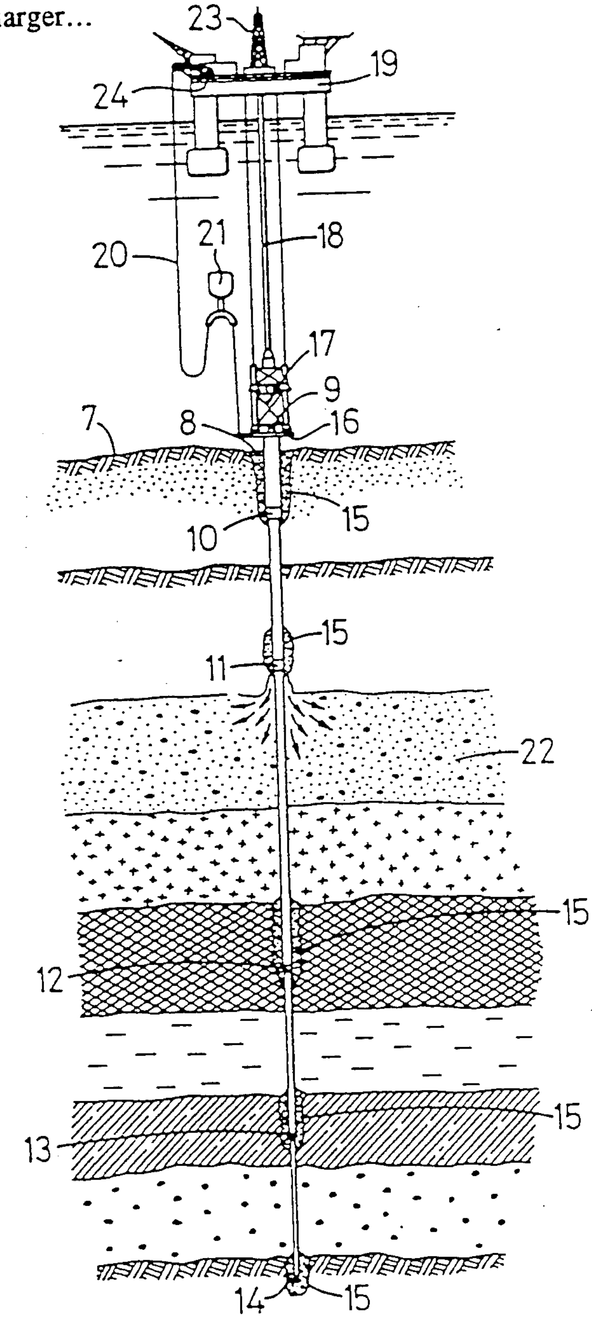


FIG. 2

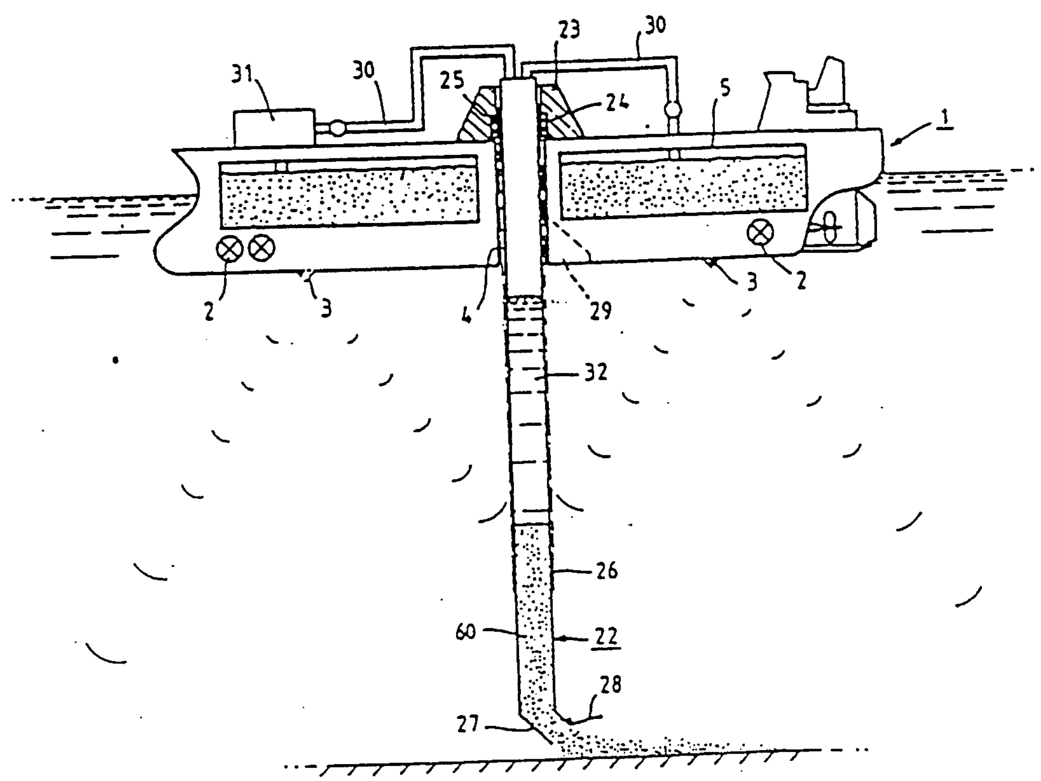
(20) Patent #5,085,277, 4 Feb., 1992, by H.P. Hopper "Sub-Sea Well Injection System"

- Primarily intended for disposal of oil-impregnated cuttings from the use of oil-based drilling mud, but also may be applicable to other unwanted slurries, via injection into the annulus of a sub-sea well, and into a porous formation.
- Employs an apparatus on a guide base surrounding the sub-sea well head.
- Typical casing strings are of decreasing diameter, 30"; 20"; 13.625"; 9.625"; and a 7" pipe extending down to the oil producing formation--but recommends using only size 13.625 and larger...



(21) Patent #5,115,751, 26 May, 1992, by A.G. Copson "Apparatus and Method for Subaqueous Waste Disposal"

- Intended for use with dredged spoils, contaminated soil, fly ash, slurry or sewage being deposited on subaqueous ground, without coming in contact with the water column.
  - Either a vertical riser/partitioned, or a tethered container for reaching 4000 to 5000 m depths.
  - Describes a 40,000T transport vehicle with moon-pool and a vented, tethered container. The size is described as 2500m³ and weight of approx. 120T.
  - Flocculants and/or stabilizers may be added to the waste during the emplacement loading operation.
  - Also describes raising and lowering of a tube capable of being raised and lowered via a notched wheel drive mechanism engaging similar features on the outer surface of the tube. The tube has an angled lower exit chute with closable hinged door. When raised, these features recess into a corresponding shaped recess of the ship. No diameter or tube length is discussed.
  - The tube partitioning, or dual tubes, permits deposition of the waste material and a "clean" cover material, in strip tracks generated by ship movement.



(22) Patent #5,127,765, 7 July, 1992, by V.D. Millgard "System for In-Situ Treatment of Underwater Contaminated Material"

- o Describes a system for application of a treatment material consisting of solidifying cement and flyash through the depth of a sedimentary silt, sludge, hazardous waste, or other contaminated material.
- o Provides for sequential/sectional treatment of confined treatable portions of the submerged bottom of water bodies in approximately 14 ft. sq. increments.
  - ■ From barge, with jack spuds, and mobile crane with crawler drive for "indexable" treatment.
  - ■ Cantilevered drive on suspension bridle used to lower and raise square casing to and from the underbed for operation of a Kelly Bar with injection and mixing blade.
  - ■ Cover Shroud within square casing to provide a watertight seal above the material to be treated.
  - ■ Requires approximately 4 to 48 hours to harden.

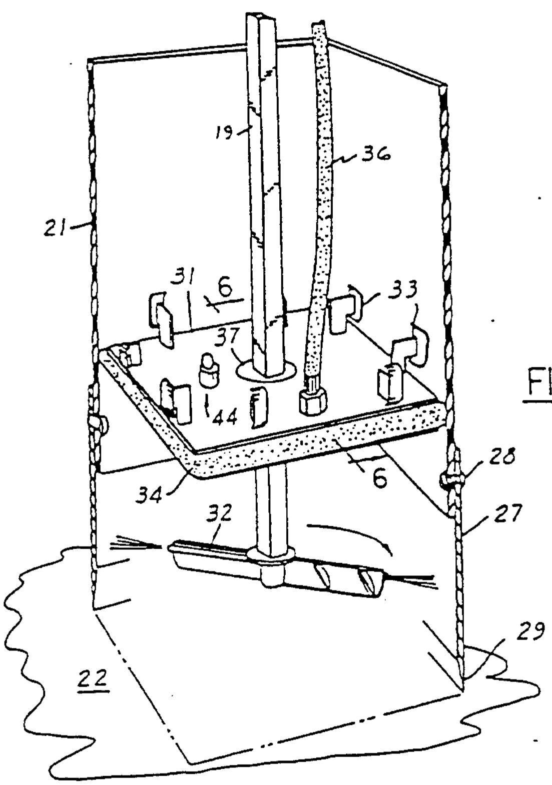


FIG.2

FIG.3

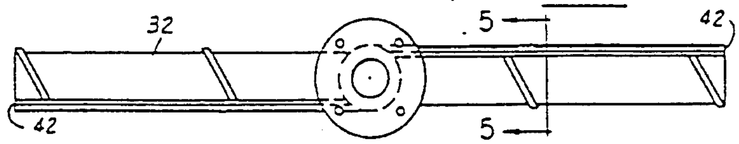
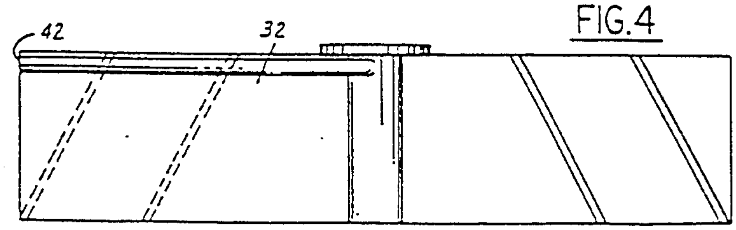


FIG.4



(23) Patent # GB 2 229 145 A, 19 Sept., 1990, by K.A.K. Eriksen "Toxic Waste Disposal to an Abyssal Plain"

- o Isolates contaminated waste from water column using a flexible container with flaps to reduce to speed of descent, aid in steering to maintain vertical descent.
- o Uses a specially built vessel or tanker to carry a slurry in special chambers sealed on top and open to the sea on the bottom. Each chamber contains a fillable flexible container and a lower trap door. Sea water is allowed to enter chamber during the container filling to minimize induced stresses in the container itself.
  - ■ Once filled, the lower trap doors are tilted open and the containers allowed to slide off and descent to rest position on the ocean floor.

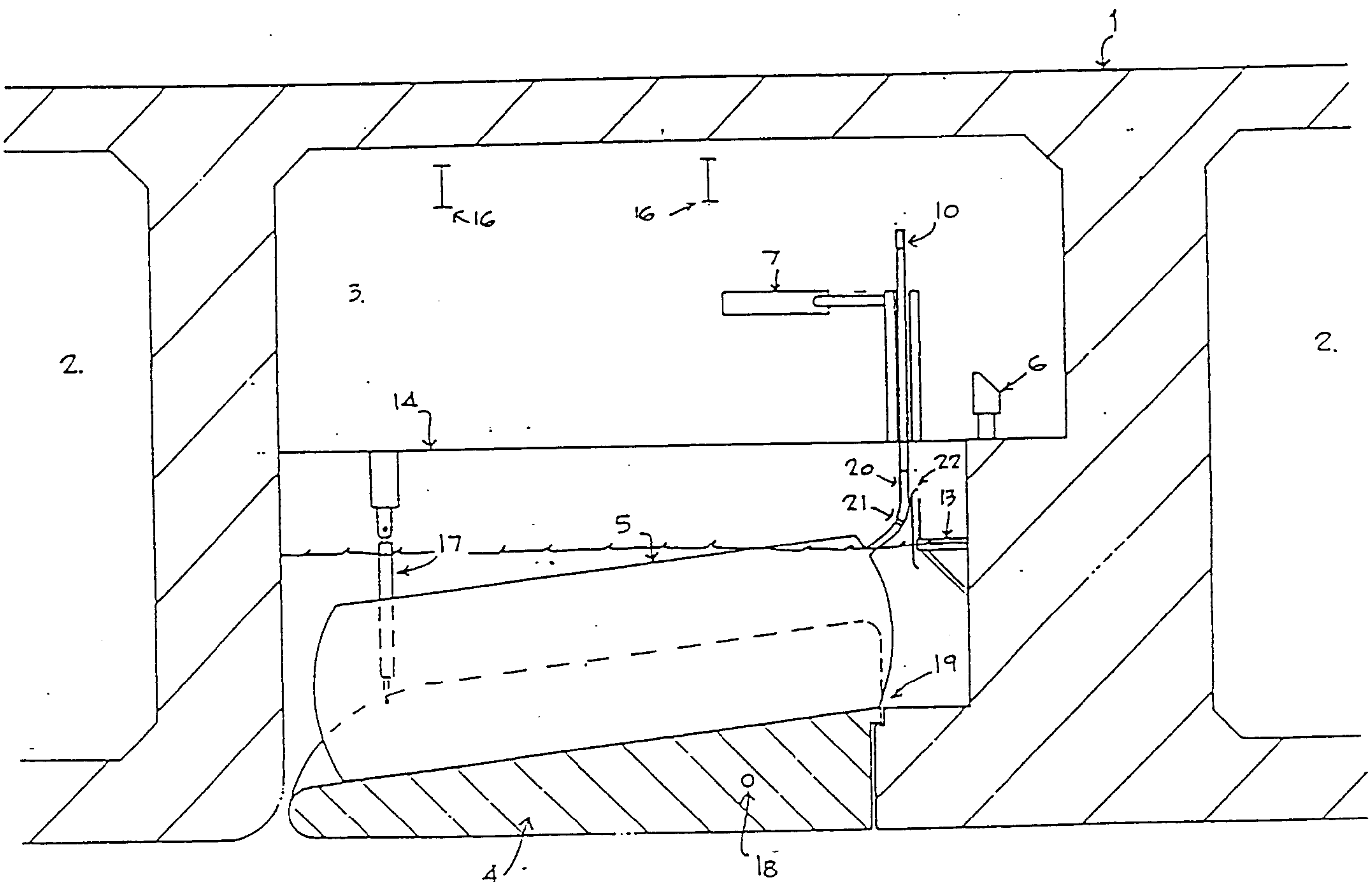
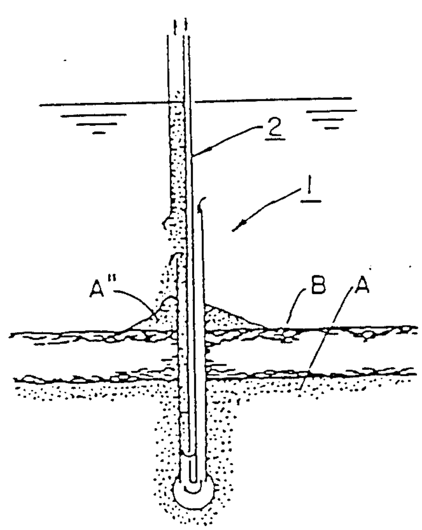


FIG. 4

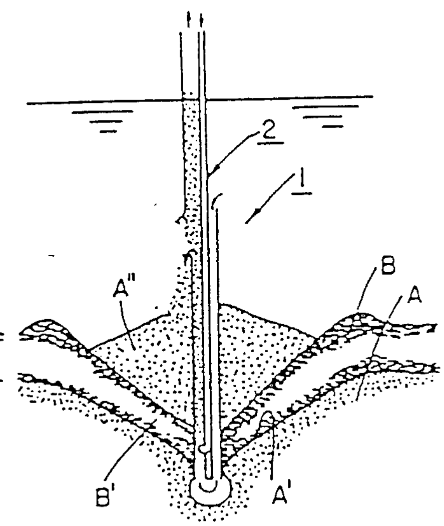
(24) Patent # 62-141219 (A), 24 Jun., 1987, N. Yamakado "Treatment Work for Sludge and its Apparatus"

- The sludge is buried beneath redeposited dredged material in a continuous process, whereby a silt trench is generated, sludge deposited and overburden reapplied using the original dredged material.
- Discusses use of a pipe with a "soil sucking mechanism"
- Very little detail provided.

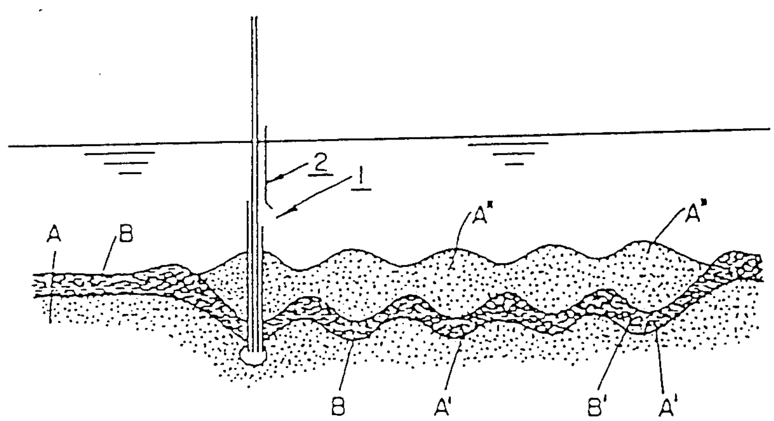
第 1 図



第 2 図

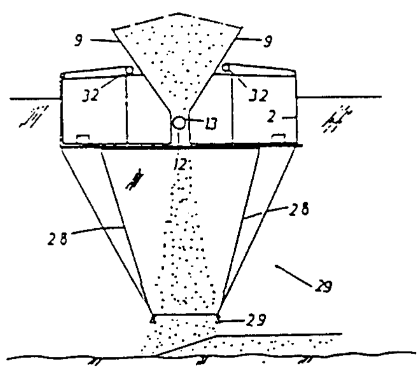


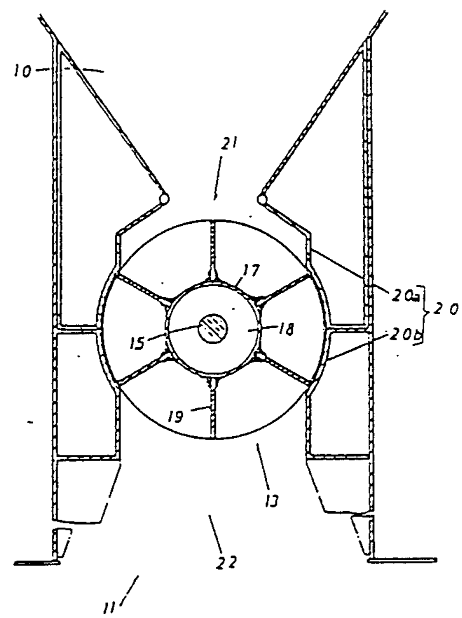
第 3 図

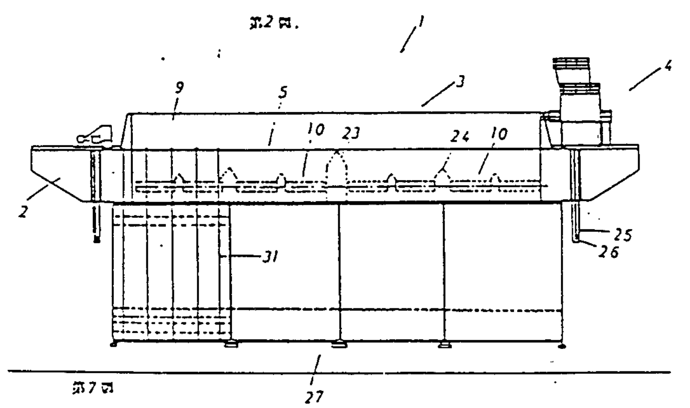


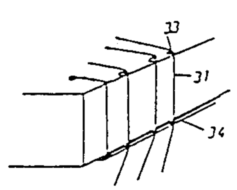
(25) Patent # 62-198595 (A), 26 Feb, 1986, by T. Hirata "Method of Spreading Bulk Into Sea and Working Ship Therefor"

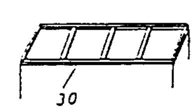
- A series of hoppers with individual rotary feeder discharging devices regulate the amount of material to be discharged, to achieve uniformity in the deposit.
  - Depicts longitudinal "shields" adjacent to the hoppers projecting downward to the sea bed, to prevent dispersion, and possibly to minimize plume generation
  - Extensive, detailed writeup, in Japanese.





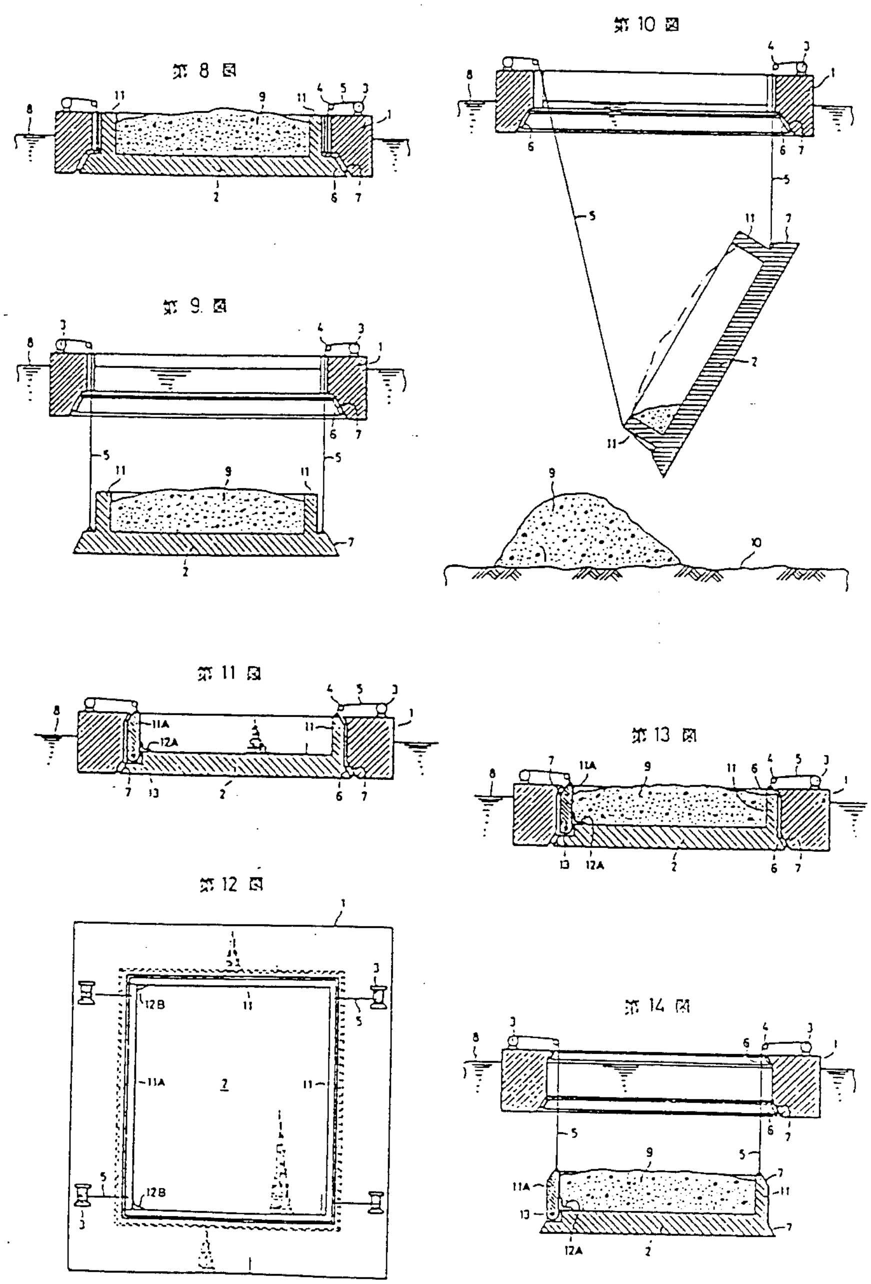






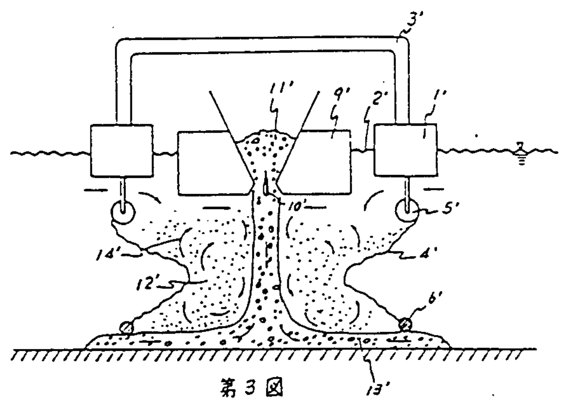
(26) Patent # 59-195487, 6 Nov., 1984, M. Nakano "Dump Boat"

- Objective is to dump a muck accurately in a desired location using a vessel with separable bottom opening capable of being lowered and tilted near the sea bottom.

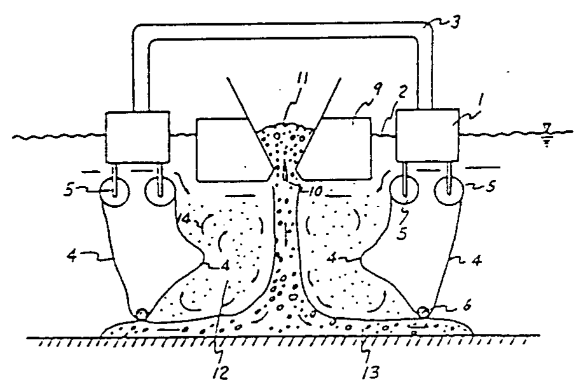


(27) Patent # 56-112386, 4 Sept., 1981, by S. Yoshii, "Floating Weight Screen Barge"

- Employed to prevent the flow of muddy water from spreading, by use of flexible, reeled screens with lower roller counterweights in contact with the upper surface of the deposited stream of earth and sand.



第3図

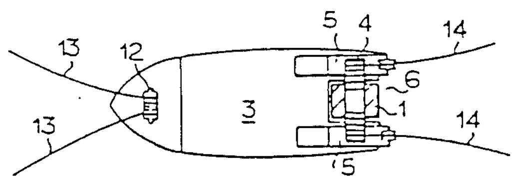


第4図

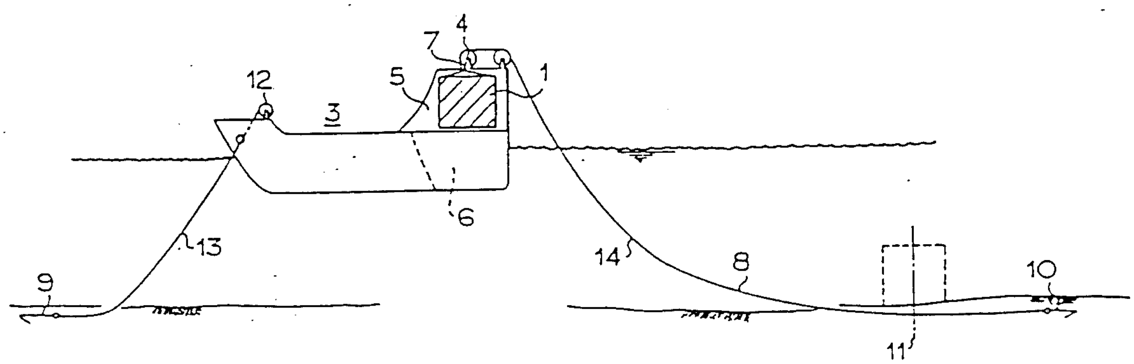
(28) Patent # 60-185692, 21 Sept., 1985, by S. Gouto "Method for Falling Heavy Object Under Water"

- Cast anchors from both the bow and stern. The heavy object is moored to one or the anchor lines, suspended, and the vessel is moved. Dropping of the heavy object is effected by reel-in on one of the anchor lines, and simultaneous payout of the anchor line with the suspended heavy object, thereby eliminating the need for a crane or winch.

第 4 図



第 3 図



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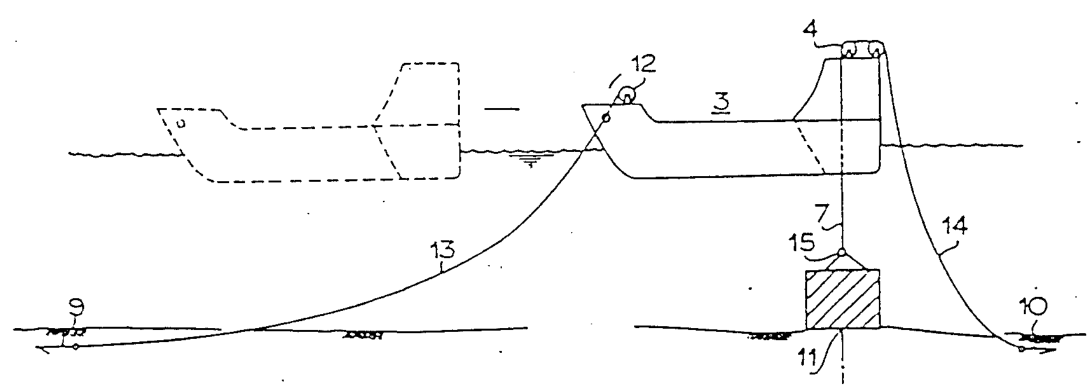
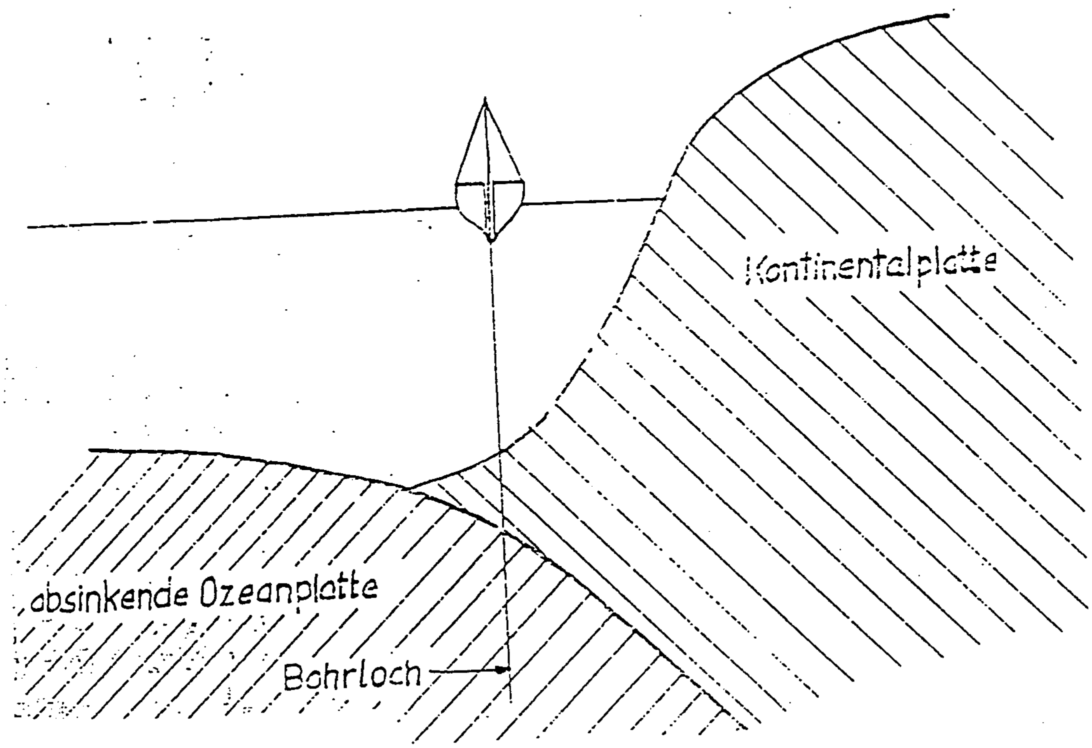


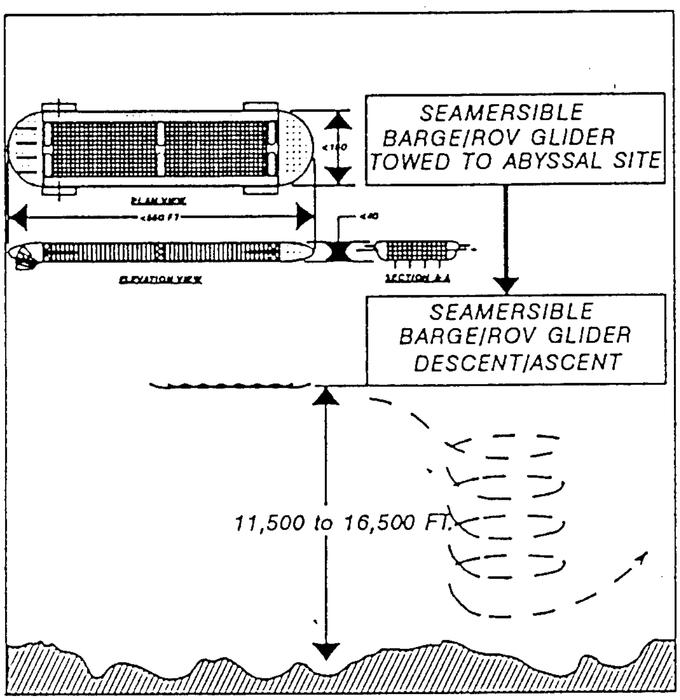
(29) Patent # DE 27 42 340 A1, 22 Mar., 1979, by E. Bohlinger "Disposal of Radioactive Waste in Cavities in Tectonic Slabs Which Slide Beneath the Earths Crust"

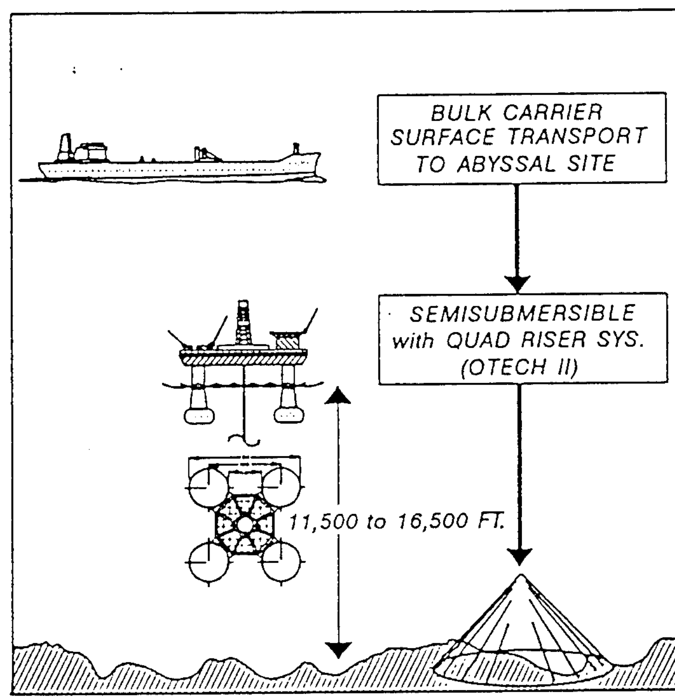
- o At the boundary between the continental shelf and the ocean bed slab, a 10cm hole is drilled and the waste inserted and capped.
- o Eliminates need for monitoring after a "certain time"



(30) Patent # (Pending), 22 Sept., 1993, W.R. Richards et al. "Transportation and Discharge of Waste to Abyssal Depths"

- o Employs either a 50,000 DWT barge/ ROV Glider, or a Quad Riser Assembly consisting of four 54 inch diameter plastic (neutrally buoyant) lines for emplacement of waste. Permits very large tonnage/hr to be deposited with minimal disturbance to the sea bed, thermally habituated and adaptable to handling either loose bulk, or "containerized" bulk.
- o For the quad riser, thermal habituation is achieved via 'OTEC' analogy, wherein water required for generation of the slurry is retrieved from depths >3000m. This minimizes transport of nutrient-rich surface waters to abyssal depths, as well as assuring thermal habituation.
  - ■ The ROV Glider uses free-flood "space-frame" cargo bays for bulk transport from the port to the disposal site, thereby permitting maximum bulk surface area to be exposed to seawater.
- o The ROV Glider is tower to the disposal site at a depth of >300ft and <1000ft. prior to release above the disposal site. It is flooded negative and follows a descending spiral glidepath to the designated site, releases its bulk cargo, and due to positive buoyancy of the empty glider, reascends to the surface.
- o The quad riser requires the use of bulk transport vessels to ferry the bulk waste from the port to the disposal site.





Appendix B

Technology Down-Select for Abyssal Plains Waste Isolation Project

APPENDIX B

I. TECHNOLOGY DOWN-SELECT FOR ABYSSAL PLAINS WASTE ISOLATION PROJECT (APWI)

A. INTRODUCTION

The evaluation of technologies and methods to achieve isolation of certain waste streams on the oceanic abyssal plains was centered around an extensive U.S. patent search of prior and current art. This search located about 128 patents of varying applicability. Of these patents, the obviously trivial were rejected outright. Those patents of a highly derivative nature were also eliminated when the parent patent could be identified. Ultimately, 98 patents were removed from consideration, most of which referenced a core group of 30 patents. These 30 patents were the starting point of a numerical assessment to further down select to the top 3-5 candidate methods of deep ocean isolation. The flowchart in Figure 1 summarizes the down select process and anchors the following description of the process' methodology.

B. METHODOLOGY

Evaluation criteria to judge the methods of isolating waste material on the oceanic abyssal plain had been developed earlier as part of an OTECH IRAD project. The criteria had been distilled by the IRAD team from OTECH'S considerable operational, engineering, and managerial experience in deep ocean military and commercial projects. These same criteria were reviewed and updated for APWI applications.

After establishing the evaluation criteria, a trade-off analysis of the 30 patents was carried out by 6 independent judge. The judges were all technically conversant in the marine industry, yet had extensive and varied backgrounds in mechanical engineering, engineering management, industrial waste disposal, and deep ocean salvage operations. The patents were scored from 1 to 5 on 20 unweighted criteria (Figure 2). For each criterion the judges had to evaluate how the candidate addressed the criterion and whether this made it a good APWI choice (a score of 5), or a poor one (a score of 1). An example of a candidate's completed data sheet is shown in Figure 3. A mediator presented an overhead view-graph giving each patent's key claims and features as well as a descriptive drawing of the patent concept. The judges were then given about 5-10 minutes to individually score the candidate patent.

The initial judging was performed against unweighted criteria to prevent any unintentional biasing of the judges assessment. After the judging of all 30 candidates, the judges then rated the 20 evaluation criteria (1 to 5, 1 being of lesser importance, 5 of greater importance) according to their absolute importance in evaluating the candidate patents. The rating of the criteria would then be used to determine appropriate weighing factors to be applied to each criterion later in the analysis, Figure 3). A candidate's

completed data sheet, tabulating both weighted and unweighted scoring, is presented in Figure 4. The remainder of the 30 candidate data sheets as well as the mediator's patent summary sheets are given following this summary. Candidate Number 22 was outright and unanimously rejected from consideration by the judges on the basis that it was wholly inappropriate for APWI.

Also in each candidate summary, the mean values and standard deviation were determined for the individual criterion scores from the six judges (see Figure 4). This was an intermediate step to see how varied the unweighted scoring was among the judges for the different criteria. Each judge's total score for the candidate was recorded and the mean and standard deviation of the six totals were calculated. Eliminating the high and low scoring judge was found to increase the confidence of the results (lessen the standard deviation) while hardly affecting average candidate score.

The unweighted raw data is recorded on each candidate's data sheet for historical reference, however, the down-select process was actually based on the candidate's weighted scoring. Weighted scores for all the candidates are summarized in Figure 5. Each judges raw score of a candidate for a particular criterion was multiplied by the determined weighting factor. The weighted scoring was then processed and analyzed just as the raw scoring had been. For all candidates as a group, the mean score and standard deviation were also calculated. Again, high and low scores were eliminated to decrease the standard deviation, while the mean value remained virtually unchanged.

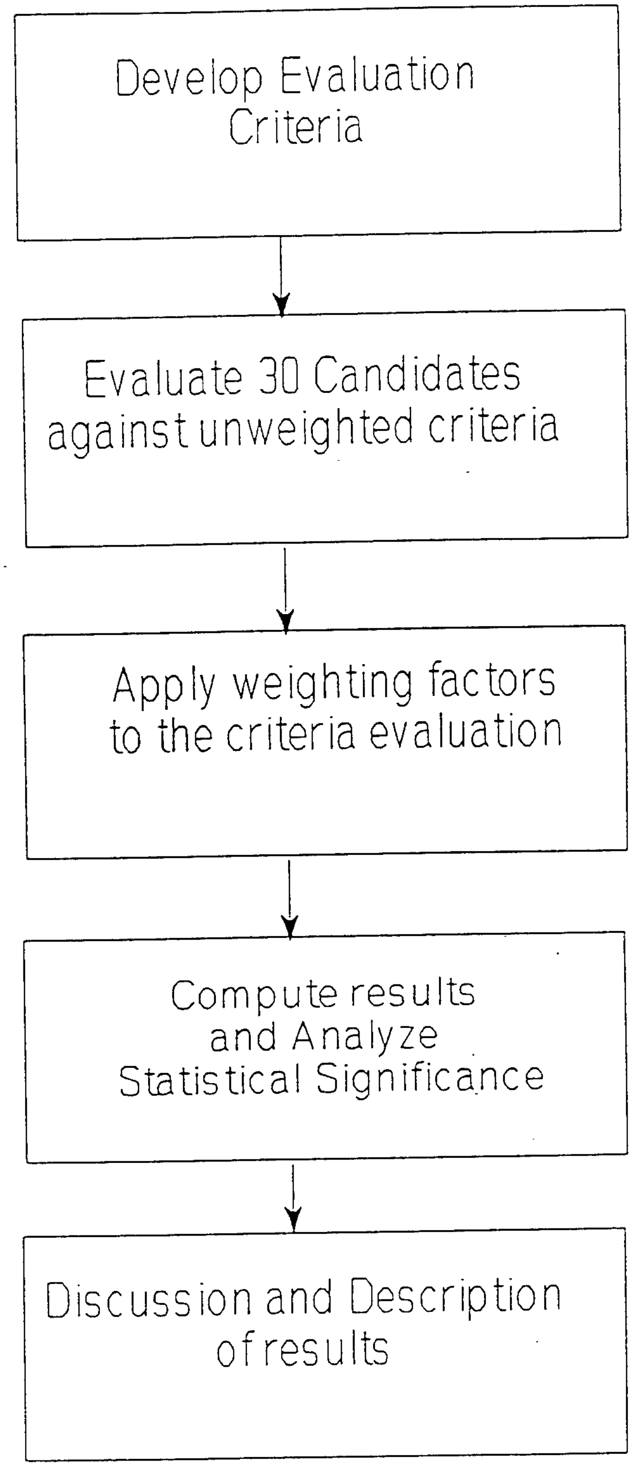
Although some clear winning concepts were now apparent by inspection of the mean scores, a more vigorous approach was used to verify those winning candidates scoring significantly above the group mean. Toward this end, the Student t-test was employed. By comparing each candidate's mean score to the mean score of all candidates together, the Student's t-test provided both a measure of the magnitude by which a candidate's score differed from the mean, as well as a measure of the level of confidence that the difference was significant. The ranking results are tabulated in Figure 6 and displayed graphically in Figure 7.

As shown in Figure 7, the seven winning candidates were as follows (in order of decreasing levels of confidence):

Candidate #15:	"Process for Hazardous Waste Containment"
Candidate #23:	"Toxic Waste Disposal to an Abyssal Plain"
Candidate #17:	"Method for the Forming and the Deposition in a Selected Place of a Bulk"
Candidate #12:	"Transportation and Disposal of Waste Material"
Candidate #11:	"Method for Chemically Solidifying and Encapsulating Hazardous Wastes in On Continuous Operation"
Candidate #5:	"Submersible Barge Retrievable Storage & Permanent Disposal System for Radioactive Waste"

Candidate #30: "Transportation and Discharge of Waste to Abyssal Depths"; (Note: this patent consists of two independent concepts)

Given the large separation in scores between these candidates and the other candidates and the high level of confidence for these scores, the investigators felt that these winning concepts represented a likely basis for further investigation into optimum APWI technology.



APWI CANDIDATE DOWNSELECT PROCESS

Figure 1

Kepner-Trego Analysis for DOR Candidate Approaches

I Evaluation Criteria: Ref. Candidate Approach #________

	1	2	3	4	5
(1). Bulk Waste Potential Exposure to Water Column	☐	☐	☐	☐	☐
(2). "In Transit" Bulk Waste Containment Integrity	☐	☐	☐	☐	☐
(3). Bulk Waste "As Deposited" Integrity/ Stability	☐	☐	☐	☐	☐
(4). Monitoring Ease vs Site/ Deposit Footprint	☐	☐	☐	☐	☐
(5). Remediation Ease vs Bulk Waste Deposit State	☐	☐	☐	☐	☐
(6). Loading/ Unloading Ease	☐	☐	☐	☐	☐
(7). Transport Ease	☐	☐	☐	☐	☐
(8). Emplacement Ease	☐	☐	☐	☐	☐
(9). Reliability/ Maintainability (Availability)	☐	☐	☐	☐	☐
(10). Hazard Potential to Navigation	☐	☐	☐	☐	☐
(11). Near Shore/ Open Ocean Weatherability (Survivability)	☐	☐	☐	☐	☐
(12). Extrapolation from Current Technology(s) (Performance/ Operational Risk)	☐	☐	☐	☐	☐
(13). Developmental/ Demonstration Program Time Duration (Experimental Validation Risk)	☐	☐	☐	☐	☐
(14). Bulk Waste % Solids Range Capability ("As Delivered" to the Port/ Staging Area)	☐	☐	☐	☐	☐
(15). Transport Cost: Port to Site	☐	☐	☐	☐	☐
(16). Emplacement Cost: Site to Sea Floor	☐	☐	☐	☐	☐
(17). Monitoring Cost: Waste Stream vs Site/ Biota Impact	☐	☐	☐	☐	☐
(18). Capital Asset Cost: Transport/ Emplacement/ Monitoring	☐	☐	☐	☐	☐
(19). Port Facility Cost: Staging/ Docking/ Handling	☐	☐	☐	☐	☐
(20). Personnel Cost: Training/ Labor Skill Category/ Etc.	☐	☐	☐	☐	☐

II Weighting Criteria: Uniform Weight (Preliminary)

III Earned Value Basis: Score from 1 to 5 (✓)

- o 1 = Very Low; 2 = Low; 3 = Medium; 4 = High; 5 = Very high

APWI CANDIDATE EVALUATION

Criteria Weighting Analysis

EVALUATION CRITERIA	RANKING SCORES #1	#2	#3	#4	#5	#6	RANKING STATS. Sum	Mean	Std. Dev.	FINAL RANK (Rounded)
1). Bulk Waste Potential Exposure to Water Column	5	5	5	5	4	5	4.83	4.83	0.41	5
2). "In Transit" Bulk Waste Containment Integrity	5	5	5	5	5	5	5.00	5.00	0.00	5
3). Bulk Waste "As Deposited" Integrity/ Stability	4	5	3	1	4	5	3.67	3.67	1.51	4
4). Monitoring Ease vs Site/ Deposit Footprint	4	2	4	4	4	5	3.83	3.83	0.98	4
5). Remediation Ease vs Bulk Waste Deposit State	2	3	2	3	3	4	2.83	2.83	0.75	3
6). Loading/ Unloading Ease	5	3	5	4	2	4	3.83	3.83	1.17	4
7). Transport Ease	5	3	5	3	2	4	3.67	3.67	1.21	4
8). Emplacement Ease	5	3	5	4	3	4	4.00	4.00	0.89	4
9). Reliability/ Maintainability (Availability)	5	4	4	5	4	3	4.17	4.17	0.75	4
10). Hazard Potential to Navigation	4	4	3	3	3	1	3.00	3.00	1.10	3
11). Near Shore/ Open Ocean Weatherability (Survivability)	4	5	3	5	4	4	4.17	4.17	0.75	4
12). Extrapolation from Current Technology(s) (Performance/ Operational Risk)	3	3	3	3	3	3	3.00	3.00	0.00	3
13). Developmental/ Demonstration Program Time Duration (Experimental Validation Risk)	3	2	2	2	2	3	2.33	2.33	0.52	2
14). Bulk Waste % Solids Range Capability ("As Delivered" to the Port/ Staging Area)	2	2	1	2	3	4	2.33	2.33	1.03	2
15). Transport Cost: Port to Site	4	4	3	2	4	4	3.50	3.50	0.84	4
16). Emplacement Cost: Site to Sea Floor	4	4	4	5	3	3	3.83	3.83	0.75	4
17). Monitoring Cost: Waste Stream vs Site/ Biota Impact	4	3	3	3	3	3	3.17	3.17	0.41	3
18). Capital Asset Cost: Transport/ Emplacement/ Monitoring	3	3.5	5	5	3	4	3.92	3.92	0.92	4
19). Port Facility Cost: Staging/ Docking/ Handling	3	3	2	4	3	2	2.83	2.83	0.75	3
20). Personnel Cost: Training/ Labor Skill Category/ Etc.	3	2	1	1	3	2	2.00	2.00	0.89	2
Raw Totals	77	68.5	68	69	66	72				
Raw Mean Score	69.92									
Raw Score Std. Deviation	4.13									

Fig 3

APWI CANDIDATE EVALUATION

APWI Candidate 1

EVALUATION CRITERIA	Weight Factor	RAW SCORES #1	#2	#3	#4	#5	#6	RAW CRITERIA STATS. Sum	Mean	Std. Dev.	WEIGHTED SCORES #1	#2	#3	#4	#5	#6	WEIGHTED CRIT. STATS. Sum	Mean	Std. Dev.
1). Bulk Waste Potential Exposure to Water Column	5	1	1	1	1	1	1	6	1.00	0.00	5	5	5	5	5	5	30	5	0.00
2). "In Transit" Bulk Waste Containment Integrity	5	1	5	3	3	1	2	15	2.50	1.52	5	25	15	15	5	10	75	12.50	7.58
3). Bulk Waste "As Deposited" Integrity/ Stability	4	1	1	1	1	1	1	6	1.00	0.00	4	4	4	4	4	4	24	4.00	0.00
4). Monitoring Ease vs Site/ Deposit Footprint	4	1	1	1	1	1	1	6	1.00	0.00	4	4	4	4	4	4	24	4.00	0.00
5). Remediation Ease vs Bulk Waste Deposit State	3	1	1	1	1	1	3	8	1.33	0.82	3	3	3	3	3	9	24	4.00	2.45
6). Loading/ Unloading Ease	4	5	5	5	4	3	3	25	4.17	0.98	20	20	20	16	12	12	100	16.67	3.93
7). Transport Ease	4	5	3	5	3	3	2	21	3.50	1.22	20	12	20	12	12	8	84	14.00	4.90
8). Emplacement Ease	4	5	5	1	1	5	2	19	3.17	2.04	20	20	4	4	20	8	76	12.67	8.16
9). Reliability/ Maintainability (Availability)	4	3	4	4	2	5	3	21	3.50	1.05	12	16	16	8	20	12	84	14.00	4.20
10). Hazard Potential to Navigation	3	3	4	4	2	3	2	18	3.00	0.89	9	12	12	6	9	6	54	9.00	2.68
11). Near Shore/ Open Ocean Weatherability (Survivability)	4	1	2	3	4	1	1	12	2.00	1.26	4	8	12	16	4	4	48	8.00	5.06
12). Extrapolation from Current Technology(s) (Performance/ Operational Risk)	3	5	4	4	3	5	1	22	3.67	1.51	15	12	12	9	15	3	66	11.00	4.52
13). Developmental/ Demonstration Program Time Duration (Experimental Validation Risk)	2	5	4	3	2	5	1	20	3.33	1.63	10	8	6	4	10	2	40	6.67	3.27
14). Bulk Waste % Solids Range Capability ("As Delivered" to the Port/ Staging Area)	2	5	5	5	2	5	1	23	3.83	1.83	10	10	10	4	10	2	46	7.67	3.67
15). Transport Cost: Port to Site	4	3	3	4	3	3	4	20	3.33	0.52	12	12	16	12	12	16	80	13.33	2.07
16). Emplacement Cost: Site to Sea Floor	4	5	5	2	2	3	4	21	3.50	1.38	20	20	8	8	12	16	84	14.00	5.51
17). Monitoring Cost: Waste Stream vs Site/ Biota Impact	3	1	1	1	2	3	1	9	1.50	0.84	3	3	3	6	9	3	27	4.50	2.51
18). Capital Asset Cost: Transport/ Emplacement/ Monitoring	4	4	2	2	2	3	4	17	2.83	0.98	16	8	8	8	12	16	68	11.33	3.93
19). Port Facility Cost: Staging/ Docking/ Handling	3	4	3	5	3	3	4	22	3.67	0.82	12	9	15	9	9	12	66	11.00	2.45
20). Personnel Cost: Training/ Labor Skill Category/ Etc.	2	4	4	3	3	3	4	21	3.50	0.55	8	8	6	6	6	8	42	7.00	1.10
Raw Totals		63	63	58	45	58	46												
Raw Mean Score		55.33																	
Raw Score Std. Deviation		8.31																	
Raw Mean Score w/o High & Low Scores (shaded)		56																	
Raw Std. Deviation w/o High & Low Scores (shaded)		7.70																	
Weighted Totals		212	219	199	159	193	160												
Weighted Mean Score		190.33																	
Weighted Score Std. Deviation		26.69																	
Weighted Mean Score w/o High & Low Scores (shaded)		191.00																	
Weighted Std. Deviation w/o High & Low Scores (shaded)		22.14																	

Fig. 4

APWI CANDIDATE EVALUATION

Weighted Score Summary

Candidate	Weighted High	Scored Low	Values #1	#2	#3	#4	Mean Score (n=6)	Std. Deviation (n=6)	Mean Score (n=4)	Std. Deviation (n=4)
1	219	159	212	199	193	160	190.33	25.59	191.00	22.14
2	241	167	172	193	175	241	198.17	34.32	195.25	31.88
3	210	194	202	203	209	202	203.33	5.79	204.00	3.37
4	207	112	204	198	125	174	170.00	41.75	175.25	35.92
5	275	199	238	223	268	274	246.17	31.34	250.75	24.30
6	243	199	212	206	229	242	221.83	18.84	222.25	16.38
7	233	178	179	204	229	216	206.50	23.97	207.00	21.28
8	265	201	222	239	220	203	225.00	24.04	221.00	14.72
9	230	169	202	198	185	190	195.67	20.40	193.75	7.68
10	253	171	219	205	205	188	206.83	28.02	204.25	12.69
11	288	207	270	282	239	279	260.83	31.54	267.50	19.67
12	295	233	234	272	254	259	257.83	23.59	254.75	15.78
13	234	187	208	206	221	202	209.67	16.18	209.25	8.22
14	225	204	216	211	206	209	211.83	7.68	210.50	4.20
15	294	248	287	283	263	293	278.00	18.50	281.50	13.00
16	250	200	241	203	246	210	225.00	23.05	225.00	21.65
17	323	238	285	283	250	271	275.00	29.93	272.25	16.07
18	206	164	202	201	164	201	189.67	19.97	192.00	18.67
19	215	150	168	175	212	185	184.17	25.45	185.00	19.30
20	261	195	219	214	234	209	222.00	22.96	219.00	10.80
21	222	190	210	218	208	197	207.50	12.19	208.25	8.66
22										
23	323	238	273	283	250	271	273.00	29.52	269.25	13.87
24	216	189	199	199	214	213	205.00	10.90	206.25	8.38
25	208	159	178	203	193	205	191.00	19.11	194.75	12.34
26	221	160	167	175	165	175	177.17	22.26	170.50	5.26
27	201	144	163	165	176	175	170.67	18.81	169.75	6.70
28	306	175	217	213	218	213	223.67	43.48	215.25	2.63
29	229	115	206	187	135	188	176.67	43.30	179.00	30.61
30	281	215	223	251	237	233	240.00	23.55	236.00	11.60
Group Mean (n=6)							215.26			
Group Std. Dev.(n=6)								31.41		
Group Mean (n=4)									214.84	
Group Std. Dev.(n=4)										31.36

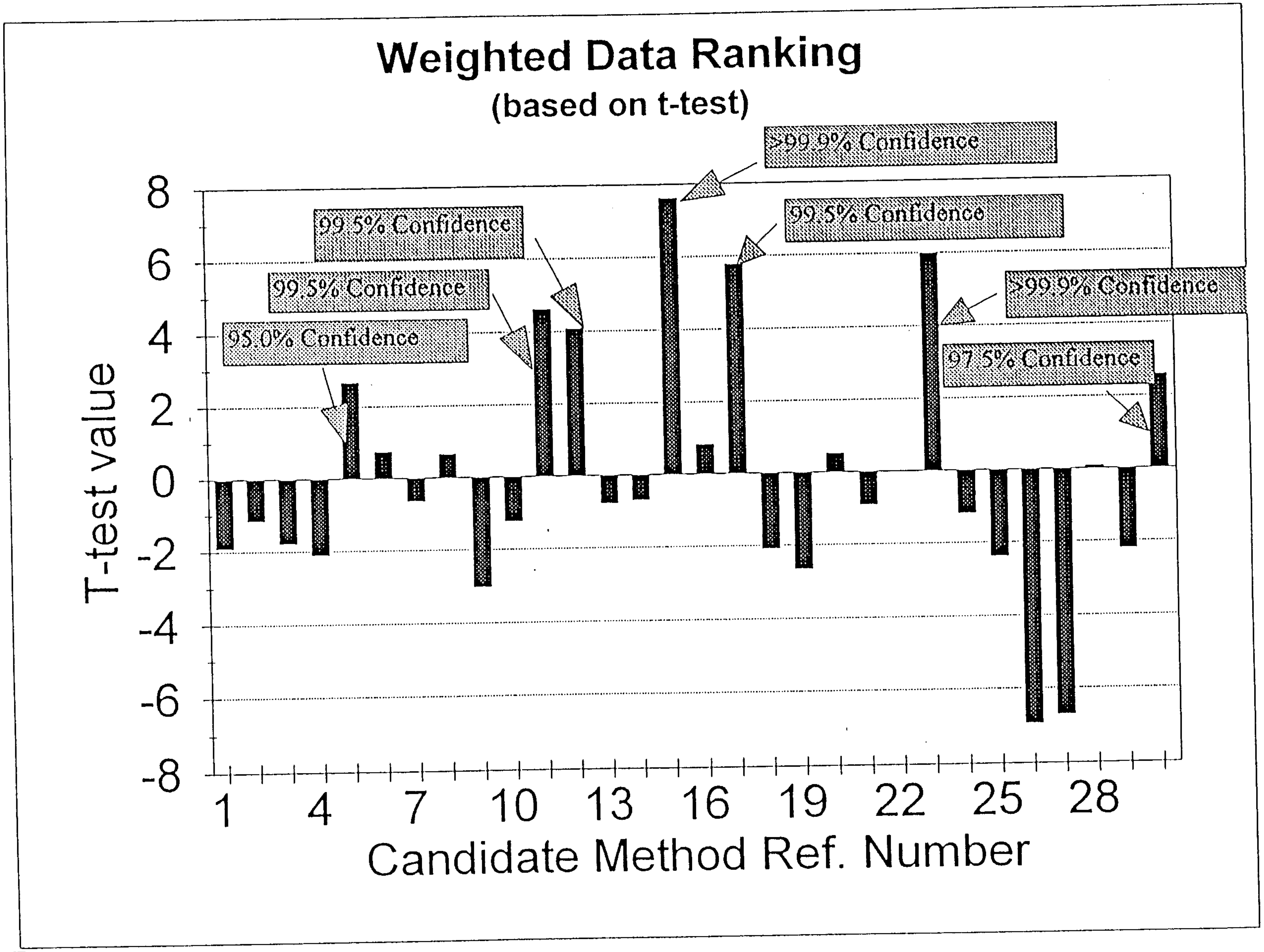
Fig. 5

APWI CANDIDATE EVALUATION

Weighted Ranking

Candidate	Cand. Smpl. Sz.,n1	Cand. Mean,X1	Cand. Std. Dev.,S1	Grp. Smpl. Sz.,n2	Grp. Mean, X2	Grp. Std. Dev., S2	Deg. Frdm.,v	t-test
1	4	191.00	22.14	29	214.84	31.36	4.85	-1.9059
2	4	195.25	31.88	29	214.84	31.36	3.85	-1.1542
3	4	204.00	3.37	29	214.84	31.36	30.86	-1.7876
4	4	175.25	35.92	29	214.84	31.36	3.66	-2.0967
5	4	250.75	24.30	29	214.84	31.36	4.51	2.6659
6	4	222.25	16.38	29	214.84	31.36	6.62	0.7378
7	4	207.00	21.28	29	214.84	31.36	5.02	-0.6461
8	4	221.00	14.72	29	214.84	31.36	7.61	0.6568
9	4	193.75	7.68	29	214.84	31.36	20.87	-3.0233
10	4	204.25	12.69	29	214.84	31.36	9.47	-1.2294
11	4	267.50	19.67	29	214.84	31.36	5.40	4.6072
12	4	254.75	15.78	29	214.84	31.36	6.94	4.0706
13	4	209.25	8.22	29	214.84	31.36	18.95	-0.7837
14	4	210.50	4.20	29	214.84	31.36	30.88	-0.7004
15	4	281.50	13.00	29	214.84	31.36	9.12	7.6386
16	4	225.00	21.65	29	214.84	31.36	4.94	0.8269
17	4	272.25	16.07	29	214.84	31.36	6.78	5.7856
18	4	192.00	18.67	29	214.84	31.36	5.70	-2.0753
19	4	185.00	19.30	29	214.84	31.36	5.50	-2.6467
20	4	219.00	10.80	29	214.84	31.36	12.26	0.5243
21	4	208.25	8.66	29	214.84	31.36	17.54	-0.9077
22								
23	4	269.25	13.87	29	214.84	31.36	8.29	6.0098
24	4	206.25	8.38	29	214.84	31.36	18.42	-1.1967
25	4	194.75	12.34	29	214.84	31.36	9.89	-2.3676
26	4	170.50	5.26	29	214.84	31.36	29.24	-6.9384
27	4	169.75	6.70	29	214.84	31.36	24.52	-6.7103
28	4	215.25	2.63	29	214.84	31.36	30.20	0.0693
29	4	179.00	30.61	29	214.84	31.36	3.92	-2.1887
30	4	236.00	11.60	29	214.84	31.36	10.90	2.5744

Fig. 6


Weighted Data Ranking
(based on t-test)
>99.9% Confidence
99.5% Confidence
99.5% Confidence
95.0% Confidence
99.5% Confidence
>99.9% Confidence
97.5% Confidence
T-test value
8
6
4
2
0
-2
-4
-6
-8
1
4
7
10
13
16
19
22
25
28
Candidate Method Ref. Number

Appendix C

Sea Floor Sediment Properties

Sample Depth (cm)	Shear Strength (psi)	Bearing Strength* (psi)	Sediment Type	Water Depth (m)	Area	Reference
0-2	0.44	2.43	clayey silt	2013	W.N.Atl	1 (area D)
0-2	0.42	2.32	clayey silt	2269	W.N.Atl.	1 (area D)
0-2	0.41	2.26	clayey silt	2452	WN. Atl.	1 (area F)
0-4	0.41	2.26	clayey silt	2452	WN. Atl.	1 (area F)
0-2	0.11	0.61	clayey silt	2434	WN. Atl.	1 (area F)
0-2	0.30	1.66	silty clay	2416	WN. Atl.	1 (area F)
0-4	0.165	0.91	silty clay	3660	N. Pac.	5 (table 1)
0-5	0.103	0.57	silty clay	5399	N. Pac.	5 (table 1)
0-5	0.159	0.88	silty clay	5175	N. Pac.	5 (table 1)
0-15	0.077	0.42	silty clay	3720	S. Pac.	5 (table 1)
0-15	0.188	1.04	clayey silt	4610	S. Pac.	5 (table 1)
5-10	0.223	1.23	clay	5660	S. Pac.	5 (table 1)
0-5	0.116	0.64	silty clay	5692	N. Pac.	5 (table 1)
0-5	0.084	0.46	clay	5399	N. Pac.	5 (table 1)
10-20	0.412	2.27	silty clay	5280	WN. Atl.	9 (core 7)
5-15	0.398	2.20	clayey silt	5310	WN. Atl.	9 (core 9)
8-18	0.242	1.34	silty clay	5234	WN. Atl.	9 (core 11)
9-19	0.341	1.88	silty clay	5252	WN. Atl.	9 (core 16)
10-20	0.341	1.88	silty clay	5197	WN. Atl.	9 (core 18)
10-17	0.480	2.65	clay	5078	WN. Atl.	9 (core 20)
10-17	0.256	1.41	clayey silt	5252	WN. Atl.	9 (core 22)
0	0.242	1.34	calc. clay	5170	WN. Atl.	1 (core 1)
5	0.258	1.42	calc. clay	5180	WN. Atl.	1 (core 2)
0-10	0.1-0.2	0.55-1.1	red clay	(?)	NE. Pac.	2 (text)
5	0.5	2.76	red clay	(?)	NE. Pac.	2 (Fig. 6)
1-2	0.1	0.55	red clay	(?)	NE. Pac.	2 (Fig. 10)
2.5	0.22	1.21	red clay	(?)	NE. Pac.	2 (Fig. 8)
10	0.174	0.96	clay	5800	WN. Atl.	7 (Fig. 3)
5	0.348	1.92	clay	5800	WN. Atl.	7 (Fig. 5)
0 (est.)	0.29	1.60	clay	5800	WN. Atl.	7 (Fig. 7)
0-10	.116-.39	.64-2.16	clay	5800	WN. Atl.	7 (Fig. 10)
5	0.128	0.71	clay	5000+	N. Pac.	8 (Fig. 3)
15	0.38	2.09	clay	5768	N. Pac.	4 (Fig. 4-3)
15	o.3	1.66	clay	5597	N. Pac.	4 (Fig. 5-3)
15	0.39	2.15	clay	5644	N. Pac.	4 (Fig. 6-3)
5	0.29	1.60	clay	5300	WN. Atl..	3 (Fig. 3)
0	0.174	0.96	clay	5400	WN. Atl.	3 (Fig. 4)
5	0.29	1.60	clay	5800	WN. Atl.	3 (Fig. 5)

References for Shear Strength Data:

1. Fleischer, P., Cross, S. L., and Egloff, Jr., J., 1991. A seafloor site survey, southwestern Bermuda Rise. Technical Note 143, Naval Oceanographic and Atmospheric Research Laboratory, 26p.

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4. Lee, H., 1980. Physical properties of northeast Pacific sediments related to sediment environment and geologic history. Mar. Geol. 38, 141-163.

5. Moore, D. G., 1962. Bearing strength and other physical properties of some shallow and deep-sea sediments from the North Pacific. Geol. Soc. Amer. Bull., 73, 1163-1166.

6. Richards, A. F., 1962. Investigations of deep-sea sediment cores. II. Mass physical properties. Tech. Rep.106. U.S. Navy Hydgrographic Office, Washington, D. C., 146p.

7. Shephard, L. E., Rutledge, A. K., Bryant, W. R., and Moran, K. M., 1987. Geotechnical characteristics of fine-grained turbidite sequences from the Nares Abyssal Plain. In: P. P. E. Weaver and J. Thomson (eds.), Geology and Geochemistry of Abyssal Plains. Geol. Soc. Amer. Spec. Pub., No. 31, 131-146.

8. Silva, A. J., Laine, E. P., Lipkin, J., Heath, G. R., and Akers, S. A., 1984. Geotechnical properties of sediments from the north central Pacific and northern Bermuda Rise. Mar. Geotechnology, 5 (3-4) 235-256.

9. Stiles, N. T., 1967. Mass physical relationships of sediments from the Hatteras Abyssal Plain. Informal Rep., IR NO. 67-8. Naval Oceanographic Office, Washington, D. C., 110p.

Physiographic Provinces: (indexed by reference number):

1. SW edge of Bermuda Rise (approx. 28°N/69°W)

2. Abyssal hills, NE Pacific (no coordinates given)

3. Greater Antilles Outer Ridge and Nares Abyssal Plain

4. Abyssal hills, NE Pacific (30°-38°N/147°-151°W)

5. One on continental slope (bearing capacity = 0.91), the rest in abyssal hill areas

6. Area D (maybe Blake-Bahama Outer Ridge judging from water depths or maybe continental slope)
   Area F (continental slope off New England, U.S.)

7. Nares Abyssal Plain

8. Abyssal hills, (approx. 31°N-158°W)

9. Blake-Bahama Outer Ridge/Hatteras Abyssal Plain (25-26°N/72-73°W)

* Bearing capacity = 5.52 x shear strength (or cohesion). The number (5.52) is from reference 5 and applies to footings where the length of footing is much greater than the breath. In the case of a square footing 7.95 would be used, and 6.57 would be used in the case of a circular footing. Herb Herrmann (Naval Facilities Engineer Service Center, Washington DC) recommended using the number 5. On the other hand, Bob Hurst (Defense Scientific Establishment, NZ Defense Force, New Zealand) uses the number 10. He also observes a good correlation between bearing strength and density for soft sediments.

Except for reference 5, I did not find one reference that provided bearing strength data (according to Herb Herrmann there just isn't much available when it comes to deep, soft sediments). In listing shear strength data, I used only measurements that were no deeper than 20 cm in the sediment. I also biased things by excluding shear strength measurements that resulted in bearing strengths of 3 psi or above.

Conversions: psi = KPa ÷ 6.89476 and psi = g/cm^2 ÷ 70.31

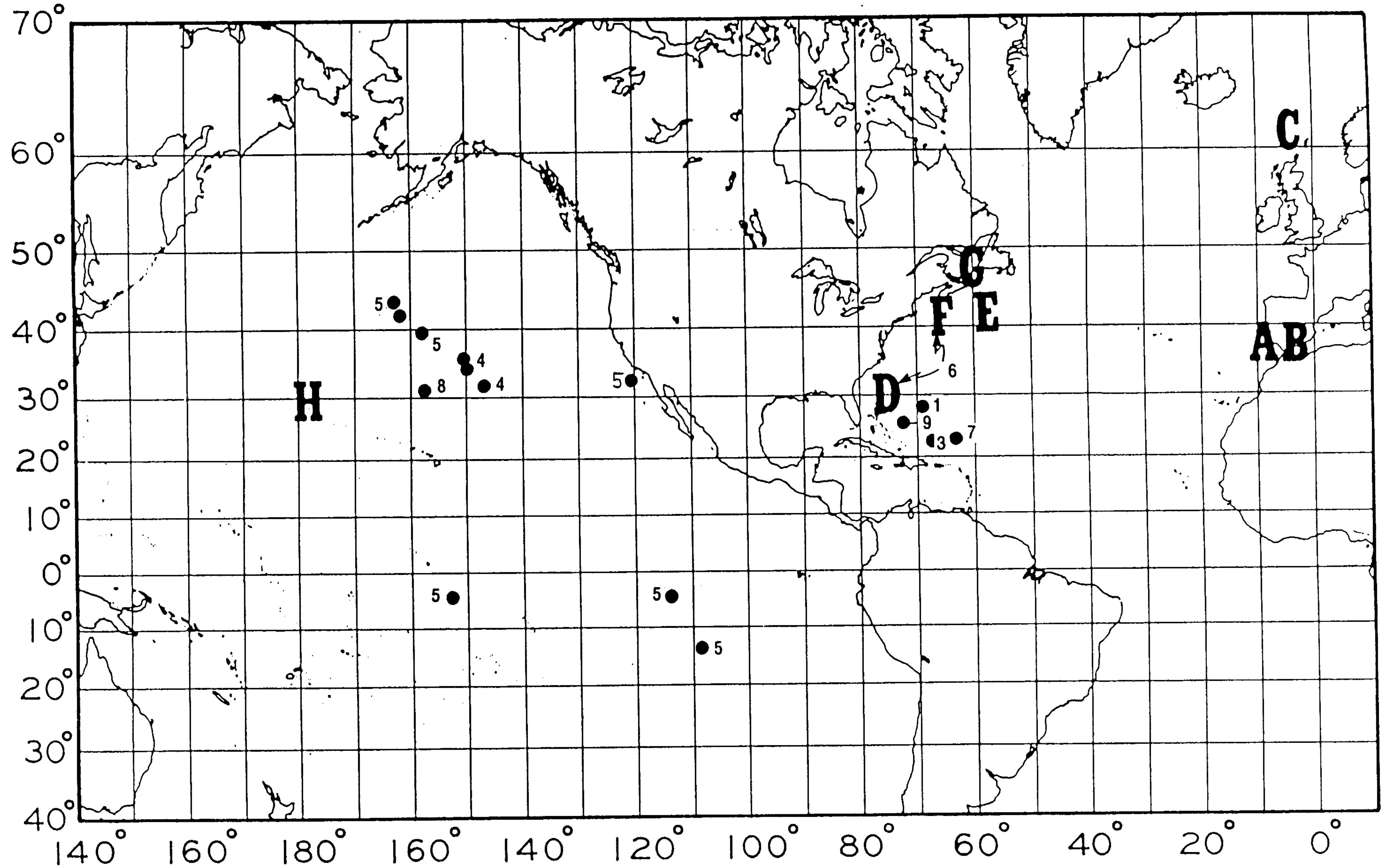

FIGURE 1. LOCATION OF AREAS FROM WHICH CORES WERE COLLECTED

Appendix D

Docking Space with Port Facilities Database

Docking Space with Port Facilities Database Field Definitions

FIELD TITLE	DEFINITION
Port	Port series volume title
Reference Number	Location of port write-up in the appropriate port series volume
Tide	Mean tidal ranges at the port location (in feet)
Length	Length alongside dock (in feet)
Depth	Depth alongside dock (in feet)
Handling Equipment	Existing equipment at dock or equipment available for use
Cargo/Present Uses	What cargo is shipped or received from that dock or other uses of the dock.
Coast	e = East Coast g = Gulf Coast w = West Coast
Load Rate	Loading rate of equipment found at the dock. If loading rate for equipment at a dock is not listed an nl will appear in that column

8/09/94

DOCKING SPACE WITH PORT FACILITIES

rt: Baltimore Ref #: 3 Tide: 1
ngth: 1020 Depth: 45
Handling Equipment:
3 st. line unloaders, 26 ton buckets, 175 ton hopper, 2 conveyors
Cargo/Present Uses: load capac 2000 lbs sqft, lighted
Coast: e Load Rate: 1500 tph

Port: Baltimore Ref #: 6 Tide: 1
Length: 2200 Depth: 32
Handling Equipment:
2 bridge cranes, clamshell buckets
Cargo/Present Uses: load capac 2000 lbs/sqfr, lighted, unused
Coast: e Load Rate: nl

Port: Baltimore Ref #: 17 Tide: 1
Length: 2860 Depth: 34
Handling Equipment:
6-45ton container handling cranes, fork lift
Cargo/Present Uses: containerized general cargo, 23 acres cont. storag
Coast: e Load Rate: nl

Port: Baltimore Ref #: 18 Tide: 1
Length: 1220 Depth: 34
Handling Equipment:
4-45 ton container handling cranes, 2-60 ton gantry cranes,
argo/Present Uses: containerized cargo, 14.5 acres cont. storage
ast: e Load Rate: nl

Port: Baltimore Ref #: 19 Tide: 1
Length: 3800 Depth: 34
Handling Equipment:
4 electric gantry cranes,
Cargo/Present Uses: general cargo, molasses, cruise vessels
Coast: e Load Rate: nl

Port: Baltimore Ref #: 21 Tide: 1
Length: 3127 Depth: 42
Handling Equipment:
7-50 ton gantry cranes
Cargo/Present Uses: containerized gen. cargo, 135 acres cont. storage
Coast: e Load Rate: nl

Port: Baltimore Ref #: 26 Tide: 1
Length: 1623 Depth: 32
Handling Equipment:
available as required
Cargo/Present Uses: used to moor hospital ship USNS Comfort
Coast: e Load Rate: nl

Port: Baltimore Ref #: 27 Tide: 1
Length: 1485 Depth: 30
ndling Equipment:
/ailable as required
Cargo/Present Uses: Coal company vessel moring, handling ship supplies
Coast: e Load Rate: nl

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: Baltimore Ref #: 28 Tide: 1
ngth: 1069 Depth: 32
ndling Equipment:
available as required
Cargo/Present Uses: Occasional receipt/shipment gen. cargo
Coast: e Load Rate: nl

Port: Baltimore Ref #: 31 Tide: 1
Length: 1253 Depth: 42
Handling Equipment:
Shiploading tower 7000 tons/hr. travels 1050 ft, 84" belt conveyor
Cargo/Present Uses: Shipment of coal by barge and vessel
Coast: e Load Rate: 7000 tph

Port: Baltimore Ref #: 38 Tide: 1
Length: 1100 Depth: 32
Handling Equipment:
15 & 18 ton gentry cranes, 4 traveling platforms, 4 freight elevat
Cargo/Present Uses: Gypsum board, forest products, containerized cargo
Coast: e Load Rate: 75000 bus/h

Port: Baltimore Ref #: 63 Tide: 1
Length: 970 Depth: 38
Handling Equipment:
2-12ton unloading towers, 40"conveyor, 6 bulldozers, 1 cuyd shovel
Cargo/Present Uses: Receipt of bulk raw sugar, mooring vessels
Coast: e Load Rate: nl

Port: Baltimore Ref #: 69 Tide: 1
Length: 950 Depth: 31
Handling Equipment:
None
Cargo/Present Uses: Not used/ poor condition/lumber storage area
Coast: e Load Rate: nl

Port: Baltimore Ref #: 70 Tide: 1
Length: 1200 Depth: 34
Handling Equipment:
2 gantry cranes, each crain has 10 ton hoist (bucket, magnet...)
Cargo/Present Uses: Containerized cargo, steel, lumber, latex,
Coast: e Load Rate: nl

Port: Baltimore Ref #: 71 Tide: 1
Length: 1212 Depth: 34
Handling Equipment:
Available on request
Cargo/Present Uses: Containerized general cargo, receipt liquid latex
Coast: e Load Rate: nl

Port: Baltimore Ref #: 72 Tide: 1
Length: 900 Depth: 35
Handling Equipment:
gantry cranes, diesel locomotive crane
rgo/Present Uses: Mooring naval vessel Cape Decision
Coast: e Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: Baltimore Ref #: 79 Tide: 1
ngth: 2056 Depth: 36
ndling Equipment:
3-40 ton container handling cranes, 100 ton gantry crane
Cargo/Present Uses: Receipt/shipment gen. containerized cargo & mach.
Coast: e Load Rate: nl

Port: Baltimore Ref #: 80 Tide: 1
Length: 1139 Depth: 31
Handling Equipment:
2-10 ton gantry cranes, 2-4ton freight elevators, 1-10 ton bridge
Cargo/Present Uses: General cargo, heavy equipment, machinery
Coast: e Load Rate: nl

Port: Baltimore Ref #: 81 Tide: 1
Length: 900 Depth: 35
Handling Equipment:
2-10 ton gantry cranes, 10 ton elevator, 10 ton electric liftbridge
Cargo/Present Uses: Handling cable, machinery, communications equip.
Coast: e Load Rate: nl

Port: Baltimore Ref #: 86 Tide: 1
Length: 900 Depth: 53
Handling Equipment:
None
Cargo/Present Uses: Mooring vessels, formerly for vessel construction
Coast: e Load Rate: nl

Port: Baltimore Ref #: 91 Tide: 1
Length: 900 Depth: 35
Handling Equipment:
1 steel hosehandling tower w/60' boom
Cargo/Present Uses: Receipt/shipment misc. bulk liquid cargo by barge
Coast: e Load Rate: nl

Port: Baltimore Ref #: 108 Tide: 1
Length: 900 Depth: 30
Handling Equipment:
1 traveling shiploading coal tower (6000 tons/hr), 96"conveyor,
Cargo/Present Uses: Shipment of coal by barge and vessel
Coast: e Load Rate: 1500-2000tph

Port: Baltimore Ref #: 109 Tide: 1
Length: 909 Depth: 42
Handling Equipment:
1 traveling shiploading tower (6000tons/hr), 84"conveyor
Cargo/Present Uses: Shipment of coal by barge and vessel
Coast: e Load Rate: 6000 tph

Port: Wilmington, NC Ref #: 7 Tide: 4
Length: 1750 Depth: 38
Handling Equipment:
40 ton container hand. cranes, 4 various size gantry cranes + addnl
rgo/Present Uses: Conventional & containerized, heavy items, forest
Coast: e Load Rate: 30 cont/hr

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: Wilmington, NC Ref #: 8 Tide: 4
ngth: 2900 Depth: 38
ndling Equipment:
3-40 ton container hand. cranes, 4 various size gantry cranes + addnl
Cargo/Present Uses: Conventional, dry bulk, scrap metal, salt, lumber
Coast: e Load Rate: 30 cont/hr

Port: Wilmington, NC Ref #: 9 Tide: 4
Length: 1213 Depth: 38
Handling Equipment:
3-40 ton container hand. cranes, 4 various size gantry cranes + addnl
Cargo/Present Uses: Conventional & containerized, heavy lift, dry bulk
Coast: e Load Rate: 30 cont/hr

Port: Morehead City, NC Ref #: 9 Tide: 3
Length: 1000 Depth: 40
Handling Equipment:
Vessel loading tower, 65"conveyor (1000-3000tph)
Cargo/Present Uses: Dry bulk materials incl. coal, and phosphoric acid
Coast: e Load Rate: 1000-3000tph

Port: Morehead City, NC Ref #: 10 Tide: 3
Length: 1281 Depth: 35
Handling Equipment:
55 forklift trucks, 20-10 ton trailers, 4 tractors, loading hoppers
Cargo/Present Uses: Conventional/containerized, asphalt, salt,fishmeal
Coast: e Load Rate: nl

Port: Morehead City, NC Ref #: 11 Tide: 3
Length: 1090 Depth: 35
Handling Equipment:
2 gantry cranes traveling 1150 feet on wharf apron
Cargo/Present Uses: Conventional/containerized, tobacco, lumber, steel
Coast: e Load Rate: nl

Port: Morehead City, NC Ref #: 12 Tide: 3
Length: 1350 Depth: 35
Handling Equipment:
2 gantry cranes traveling 1150 feet on wharf apron
Cargo/Present Uses: Conventional/containerized, tobacco logs, potash
Coast: e Load Rate: nl

Port: Delaware R Wilmingtn Ref #: 12 Tide: 6
Length: 3060 Depth: 35
Handling Equipment:
35 ton gantry crane, 1 bulk unloading tower (500tph), 100 T gentry crn
Cargo/Present Uses: convent/containerized, autos, bananas, chemicals..
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 49 Tide: 6
Length: 2254 Depth: 38
Handling Equipment:
steel structures with pipeline loading arms
argo/Present Uses: Crude oil, naphtha by tanker and barge
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 90 Tide: 6
ngth: 927 Depth: 34
ndling Equipment:
40- 2-25T gasoline fork lift trucks
Cargo/Present Uses: General and containerized cargo
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 91 Tide: 6
Length: 960 Depth: 40
Handling Equipment:
Electric traveling shiploader w/ telescopic chute, hose handle derrick
Cargo/Present Uses: Coal, diesel fuel for railroad locomotives
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 95 Tide: 6
Length: 3101 Depth: 35
Handling Equipment:
1 heavy lift container crane, 2-45T container cranes, 2 top lift truck
Cargo/Present Uses: Conventional/containerized, rollon/rolloff, steel
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 100 Tide: 6
Length: 1500 Depth: 33
Handling Equipment:
11 electric elevators in storage sheds, portable 36" conveyors
Cargo/Present Uses: Shipment of bagged coommodities including grain
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 141 Tide: 6
Length: 3172 Depth: 40
Handling Equipment:
2-45T container cranes, 69 gas fork lift trucks, 5 mobile hoists
Cargo/Present Uses: Conventional/containerized, roll on and roll-off
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 150 Tide: 6
Length: 1200 Depth: 36
Handling Equipment:
Cargo beams on roof of transit shed,
Cargo/Present Uses: Conventional/containerized, motor vehicles, bulk
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 158 Tide: 6
Length: 1000 Depth: 40
Handling Equipment:
None
Cargo/Present Uses: Mooring Vessels
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 159 Tide: 6
Length: 1130 Depth: 40
Handling Equipment:
gantry cranes with hoppers, 54"belt conveyor
rgo/Present Uses: iron ore, ferromanganese, fuel oil, coal, coke
Coast: e Load Rate: 1000 tph ea

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: Delaware R Philadelp Ref #: 160 Tide: 6
ngth: 1001 Depth: 40
.ndling Equipment:
2 gantry cranes with accessories
Cargo/Present Uses: coal, coke, iron, semifinished steel
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 196 Tide: 6
Length: 2290 Depth: 35
Handling Equipment:
1-85T bulk cargo crane, 2-25T gantry cranes, front end loaders
Cargo/Present Uses: Conventional/containerized, steel, lumber, ores
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 203 Tide: 6
Length: 1100 Depth: 35
Handling Equipment:
2 gantry cranes, 3 straddle carriers for stacking containers
Cargo/Present Uses: conventional/containerized cargo
Coast: e Load Rate: nl

Port: Delaware R Philadelp Ref #: 207 Tide: 6
Length: 900 Depth: 45
Handling Equipment:
2-40T container handling cranes, 2 150T mobile cranes, 100 forklifts
Cargo/Present Uses: Containerized cargo
Coast: e Load Rate: 30 cont/hr

Port: Charleston Ref #: 9 Tide: 5
Length: 1400 Depth: 35
Handling Equipment:
Gantry crane, 28 fork lift trucks, 5 mobile cranes
Cargo/Present Uses: Conventional/containerized cargo, heavy lift items
Coast: e Load Rate: nl

Port: Charleston Ref #: 14 Tide: 5
Length: 900 Depth: 35
Handling Equipment:
2 40T container handling cranes, 3 container handlers, 3 gantry cranes
Cargo/Present Uses: Containerized general cargo
Coast: e Load Rate: 30 cont/hr

Port: Charleston Ref #: 16 Tide: 5
Length: 1500 Depth: 35
Handling Equipment:
1 shear leg derrick, level luffing cranes, mobile cranes, fork lift tr
Cargo/Present Uses: Conventional general cargo & heavy lift items
Coast: e Load Rate: nl

Port: Charleston Ref #: 35 Tide: 5
Length: 2460 Depth: 38
Handling Equipment:
Container handlers, 34 fork lift trucks, mobile cranes
.rgo/Present Uses: Conventional/containerized cargo
Coast: e Load Rate: nl

Port: Charleston Ref #: 45 Tide: 5
ngth: 2427 Depth: 38
ndling Equipment:
4- 40 long ton container handling cranes, 14 fork lift trucks
Cargo/Present Uses: Containerized general cargo
Coast: e Load Rate: nl

Port: Savannah Ref #: 22 Tide: 7
Length: 1178 Depth: 38
Handling Equipment:
Gantry crane, additional equipment available as requested
Cargo/Present Uses: Conventional/containerized cargo
Coast: e Load Rate: nl

Port: Savannah Ref #: 25 Tide: 7
Length: 975 Depth: 38
Handling Equipment:
5 gantry cranes
Cargo/Present Uses: Conventional/containerized cargo
Coast: e Load Rate: nl

Port: Savannah Ref #: 26 Tide: 7
Length: 1128 Depth: 34
Handling Equipment:
100 T mobile crane, container lift trucks, gantry cranes, + additional
Cargo/Present Uses: Conventional/containerized cargo
Coast: e Load Rate: nl

Port: Savannah Ref #: 27 Tide: 7
Length: 1666 Depth: 38
Handling Equipment:
5 gantry cranes, container lift trucks, + additional as required
Cargo/Present Uses: Conventional/containerized, liquid latex
Coast: e Load Rate: nl

Port: Savannah Ref #: 41 Tide: 7
Length: 2358 Depth: 38
Handling Equipment:
9 container cranes, 6 container bridge cranes, container trucks
Cargo/Present Uses: Containerized, roll-on/roll-off
Coast: e Load Rate: nl

Port: Jacksonville Ref #: 9 Tide: 5
Length: 924 Depth: 40
Handling Equipment:
992 T traveling bridge crane, 2 gantry cranes
Cargo/Present Uses: Not used
Coast: e Load Rate: nl

Port: Jacksonville Ref #: 10 Tide: 5
Length: 2950 Depth: 38
Handling Equipment:
container handling cranes, 2 container stackers, 2 mobile ramps
rgo/Present Uses: Conventional/containerized, roll-on/roll-off, auto
Coast: e Load Rate: nl

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: Jacksonville Ref #: 11 Tide: 5
ngth: 1750 Depth: 38
.ndling Equipment:
100 T gantry crane, 50T gantry crane
Cargo/Present Uses: Conventional general cargo, autos, steel, paper
Coast: e Load Rate: nl

Port: Jacksonville Ref #: 35 Tide: 5
Length: 1100 Depth: 36
Handling Equipment:
100 T gantry crane, 50 T gantry crane, 6 cont. handlers, 30 lift truck
Cargo/Present Uses: Conventional/containerized cargo
Coast: e Load Rate: nl

Port: Jacksonville Ref #: 36 Tide: 5
Length: 1200 Depth: 36
Handling Equipment:
Municipal docks railway tracks
Cargo/Present Uses: Conventional/containerized cargo, molasses, coffee
Coast: e Load Rate: nl

Port: Jacksonville Ref #: 37 Tide: 5
Length: 1200 Depth: 36
Handling Equipment:
2 container handling traveling cranes, yard hustlers
Cargo/Present Uses: Containerized general cargo
Coast: e Load Rate: nl

Port: Boston Ref #: 26 Tide: 9
Length: 900 Depth: 37
Handling Equipment:
Surface track Boston & Maine RR connection
Cargo/Present Uses: Petroleum prods, loading barges for bunkering ves
Coast: e Load Rate: nl

Port: Boston Ref #: 54 Tide: 9
Length: 1100 Depth: 40
Handling Equipment:
2 container handling cranes, 4- 50 T mobile container cranes,
Cargo/Present Uses: Containerized general cargo
Coast: e Load Rate: 30 cont/hr

Port: Boston Ref #: 74 Tide: 9
Length: 1200 Depth: 40
Handling Equipment:
Surface track, 2 track wells, 2 depressed tracks Consolidated RR
Cargo/Present Uses: Mooring excursion boats & cruise vessels
Coast: e Load Rate: nl

Port: Boston Ref #: 76 Tide: 9
Length: 910 Depth: 32
Handling Equipment:
gantry cranes, 1 15T mobile crane
.rgo/Present Uses: Mooring vessels for repair, conversion, outfitting
Coast: e Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: Boston Ref #: 77 Tide: 9
ngth: 910 Depth: 31
ndling Equipment:
4 gantry cranes, 1 15T mobile crane
Cargo/Present Uses: Mooring vessels for repair, conversion, outfitting
Coast: e Load Rate: nl

Port: Boston Ref #: 78 Tide: 9
Length: 2700 Depth: 38
Handling Equipment:
Trackage connects w/ consolidated RR
Cargo/Present Uses: Dry bulk commodities
Coast: e Load Rate: nl

Port: Boston Ref #: 79 Tide: 9
Length: 900 Depth: 39
Handling Equipment:
Tracks Consolidated RR
Cargo/Present Uses: Occasional mooring of vessels
Coast: e Load Rate: nl

Port: Boston Ref #: 82 Tide: 9
Length: 964 Depth: 35
Handling Equipment:
Cargo outriggers for tackle on roof of warehouse
Cargo/Present Uses: Miscellaneous bulk commodities, mooring
Coast: e Load Rate: nl

Port: Boston Ref #: 83 Tide: 9
Length: 974 Depth: 35
Handling Equipment:
Cargo outriggers for tackle on roof of warehouse
Cargo/Present Uses: Miscellaneous bulk commodities, mooring
Coast: e Load Rate: nl

Port: Boston Ref #: 85 Tide: 9
Length: 1641 Depth: 35
Handling Equipment:
4 surface tracks, Consolidated RR
Cargo/Present Uses: Miscellaneous bulk commodities, mooring
Coast: e Load Rate: nl

Port: Boston Ref #: 93 Tide: 9
Length: 1000 Depth: 40
Handling Equipment:
2 40 T container handling cranes
Cargo/Present Uses: Containerized general cargo
Coast: e Load Rate: nl

Port: Boston Ref #: 95 Tide: 9
Length: 1200 Depth: 40
Handling Equipment:
ailable as required
argo/Present Uses: General cargo
Coast: e Load Rate: nl

8/09/94

DOCKING SPACE WITH PORT FACILITIES

ort: Miami Ref #: 14 Tide: 2
ngth: 2600 Depth: 36
.dling Equipment:
5 passenger terminals, 4 customs inspection stations, parking lots
argo/Present Uses: Mooring cruise vessels, boarding passengers
oast: e Load Rate: nl

Port: Miami Ref #: 15 Tide: 2
Length: 1920 Depth: 36
Handling Equipment:
Equipment furnished
Cargo/Present Uses: Mooring cruise vessels, containerized cargo
Coast: e Load Rate: nl

Port: Miami Ref #: 16 Tide: 2
Length: 1680 Depth: 36
Handling Equipment:
Equipment furnished
Cargo/Present Uses: Conventional/containerized, roll-on/off, mooring
Coast: e Load Rate: nl

Port: Miami Ref #: 17 Tide: 2
Length: 900 Depth: 28
Handling Equipment:
Equipment furnished
Cargo/Present Uses: Conventional/containerized, roll-on/off
Coast: e Load Rate: nl

ort: Miami Ref #: 20 Tide: 2
Length: 3400 Depth: 36
Handling Equipment:
6- container handling cranes
Cargo/Present Uses: Containerized cargo
Coast: e Load Rate: 40 cont/hr

Port: Miami (Canaveral) Ref #: 2 Tide:
Length: 1060 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Mooring curise vessels, boarding passengers
Coast: e Load Rate: nl

Port: Miami (Canaveral) Ref #: 3 Tide:
Length: 1340 Depth: 35
Handling Equipment:
Equipment furnished
Cargo/Present Uses: General cargo, paper products, asphalt, frozen foo
Coast: e Load Rate: nl

Port: Miami (Canaveral) Ref #: 25 Tide:
Length: 1140 Depth: 36
Handling Equipment:
0T crawler crane, 70, 55T crawler crane, front end loader
rgo/Present Uses: Scrap metal, general cargo, mooring cruise vessels
Coast: e Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: New York Ref #: 62 Tide: 5
ngth: 1324 Depth: 35
ndling Equipment:
None
Cargo/Present Uses: Not used for handling waterborne commerce
Coast: e Load Rate: nl

Port: New York Ref #: 63 Tide: 5
Length: 1307 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Transient mooring
Coast: e Load Rate: nl

Port: New York Ref #: 64 Tide: 5
Length: 1293 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Not used for handling waterborne commerce
Coast: e Load Rate: nl

Port: New York Ref #: 72 Tide: 5
Length: 1005 Depth: 35
Handling Equipment:
Available as required
Cargo/Present Uses: General cargo
Coast: e Load Rate: nl

Port: New York Ref #: 73 Tide: 5
Length: 1118 Depth: 35
Handling Equipment:
2- 56T container handling cranes w/283ft travel length
Cargo/Present Uses: Conventional/containerized, roll-on/roll-off
Coast: e Load Rate: 10-20 cont/h

Port: New York Ref #: 75 Tide: 5
Length: 1493 Depth: 28
Handling Equipment:
None
Cargo/Present Uses: Receipt of fuel oil, mooring gas turbine generator
Coast: e Load Rate: nl

Port: New York Ref #: 77 Tide: 5
Length: 1440 Depth: 32
Handling Equipment:
10 2.5-4T forklift trucks
Cargo/Present Uses: Coffee
Coast: e Load Rate: nl

Port: New York Ref #: 78 Tide: 5
Length: 1180 Depth: 30
Handling Equipment:
lk cement storage vessel, conveyor (1000tph)
rgo/Present Uses: Receipt of cement
Coast: e Load Rate: 1000 tph

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: New York Ref #: 101 Tide: 5
ngth: 1000 Depth: 31
ndling Equipment:
None
Cargo/Present Uses: Receipt of fish
Coast: e Load Rate: nl

Port: New York Ref #: 102 Tide: 5
Length: 1128 Depth: 31
Handling Equipment:
None
Cargo/Present Uses: Receipt of fish
Coast: e Load Rate: nl

Port: New York Ref #: 103 Tide: 5
Length: 1078 Depth: 50
Handling Equipment:
2 50T gantry cranes, 3 crawlers, 2 mobile cranes
Cargo/Present Uses: Mooring vessels for repair
Coast: e Load Rate: nl

Port: New York Ref #: 124 Tide: 5
Length: 910 Depth: 32
Handling Equipment:
Available as required
Cargo/Present Uses: General cargo, mooring vessels for repair
Coast: e Load Rate: nl

ort: New York Ref #: 126 Tide: 5
Length: 1400 Depth: 33
Handling Equipment:
Container top lift trucks/forklift trucks, cranes available as requred
Cargo/Present Uses: Conventional/containerized, mooring vessels
Coast: e Load Rate: nl

Port: New York Ref #: 131 Tide: 5
Length: 1200 Depth: 40
Handling Equipment:
Bulk cement storage vessel with 5 ship unloaders, additional if requir
Cargo/Present Uses: Receipt of cement, conventional/containerized carg
Coast: e Load Rate: 250 tph

Port: New York Ref #: 363 Tide: 5
Length: 1100 Depth: 32
Handling Equipment:
2- 9T passenger elevators, 2- 4T freight elevators, escalators
Cargo/Present Uses: Passenger landing, mooring cruise vessels
Coast: e Load Rate: nl

Port: New York Ref #: 364 Tide: 5
Length: 1100 Depth: 32
Handling Equipment:
9T passenger elevators, 2- 4T freight elevators, escalators
rgo/Present Uses: Passenger landing, mooring cruise vessels
Coast: e Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: New York Ref #: 365 Tide: 5
ngth: 1100 Depth: 32
ndling Equipment:
2- 9T passenger elevators, 2- 4T freight elevators, escalators
Cargo/Present Uses: Passenger landing, mooring cruise vessels
Coast: e Load Rate: nl

Port: New York Ref #: 372 Tide: 5
Length: 1500 Depth: 40
Handling Equipment:
2- 12" pipelines, concrete storage tanks (1,219,100 gal) (1988)
Cargo/Present Uses: Shipment of sludge by vessel
Coast: e Load Rate: nl

Port: New York Ref #: 387 Tide: 5
Length: 955 Depth: 27
Handling Equipment:
None
Cargo/Present Uses: Not used (plans called for removal of pier)
Coast: e Load Rate: nl

Port: New York Ref #: 398 Tide: 5
Length: 1800 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Not used
Coast: e Load Rate: nl

ort: New York Ref #: 402 Tide: 5
Length: 1000 Depth: 34
Handling Equipment:
2- pedestal cranes, 80T crawler, 72" conveyor, front end loaders
Cargo/Present Uses: Scrap-metal by barge and vessel
Coast: e Load Rate: 1800 tph

Port: New York Ref #: 409 Tide: 5
Length: 1800 Depth: 40
Handling Equipment:
4- 40T container cranes, 2 40T container bridge cranes, 96 fork lifts
Cargo/Present Uses: Containerized general cargo
Coast: e Load Rate: 25 cont/hr

Port: New York (Newark) Ref #: 498 Tide: 5
Length: 1400 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Automobiles, heavy lift items
Coast: e Load Rate: nl

Port: New York (Newark) Ref #: 504 Tide: 5
Length: 1128 Depth: 35
Handling Equipment:
ailable as required
rgo/Present Uses: Steel prods, automobiles
Coast: e Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

ort: New York (Newark) Ref #: 505 Tide: 5
ngth: 1374 Depth: 35
ndling Equipment:
Available as required
Cargo/Present Uses: Automobiles, mooring barges
Coast: e Load Rate: nl

Port: New York (Newark) Ref #: 509 Tide: 5
Length: 927 Depth: 35
Handling Equipment:
As required
Cargo/Present Uses: Salt, scrap metal
Coast: e Load Rate: nl

Port: New York (Newark) Ref #: 511 Tide: 5
Length: 2150 Depth: 34
Handling Equipment:
As required
Cargo/Present Uses: Soda ash, mooring vessels
Coast: e Load Rate: nl

Port: New York (Newark) Ref #: 513 Tide: 5
Length: 2400 Depth: 35
Handling Equipment:
7- 12.5 T cargo beams, additional as required
Cargo/Present Uses: Bulk cement, coal, mooring barges
Coast: e Load Rate: nl

ort: New York (Newark) Ref #: 518 Tide: 5
Length: 3059 Depth: 35
Handling Equipment:
3- 40T container handling cranes, fork lifts, 33 yard hustlers
Cargo/Present Uses: Conventional/containerized
Coast: e Load Rate: 20 cont/hr

Port: New York (Newark) Ref #: 521 Tide: 5
Length: 2875 Depth: 32
Handling Equipment:
3- 30T container handling cranes, 8- forklift trucks, 27 yard hustlers
Cargo/Present Uses: Containerized and roll-on/roll-off, vehicles
Coast: e Load Rate: 25 cont/hr

Port: New York (Newark) Ref #: 522 Tide: 5
Length: 2000 Depth: 35
Handling Equipment:
2- 40T & 2- 30T container handling cranes, 30 fork lift trucks
Cargo/Present Uses: Containerized, heavy lift items
Coast: e Load Rate: 25 cont/hr

Port: New York (Newark) Ref #: 523 Tide: 5
Length: 965 Depth: 35
Handling Equipment:
30T container handling cranes, 5- 31.5T straddle carriers, frk lift
rgo/Present Uses: Containeried, roll-on/roll-off
Coast: e Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: New York (Newark) Ref #: 526 Tide: 5
ngth: 3150 Depth: 38
ndling Equipment:
3- 40T container handling cranes, 7- 40T container lift trucks, stckrs
Cargo/Present Uses: Containerized, heavy lift items
Coast: e Load Rate: 25 cont/hr

Port: New York (Newark) Ref #: 527 Tide: 5
Length: 2019 Depth: 40
Handling Equipment:
6- 40T container handling cranes, turntable, 60 yard hustlers
Cargo/Present Uses: Containerized general cargo
Coast: e Load Rate: 24 cont/hr

Port: New York (Newark) Ref #: 536 Tide: 5
Length: 1280 Depth: 40
Handling Equipment:
Steel tower with electrically operated hose hndling winches
Cargo/Present Uses: Crude oil, petroleum products, chemicals, alcohol
Coast: e Load Rate: nl

Port: New York (Newark) Ref #: 568 Tide: 5
Length: 900 Depth: 28
Handling Equipment:
2- 8" swivel jointed loading arms
Cargo/Present Uses: Petroleum prods
Coast: e Load Rate: nl

Port: New York (Newark) Ref #: 600 Tide: 5
Length: 1100 Depth: 32
Handling Equipment:
2- hydraulic telescopic boom derricks for handling hose, 12" load arm
Cargo/Present Uses: Petroleum prods
Coast: e Load Rate: nl

Port: New York (Newark) Ref #: 603 Tide: 5
Length: 2512 Depth: 40
Handling Equipment:
7- 40T container handling cranes, 6- container lift trucks, 60 forklft
Cargo/Present Uses: Containerized general cargo, bankrupcy of ship act
Coast: e Load Rate: 10-20 cont/h

Port: Tampa Ref #: 3 Tide: 1
Length: 1500 Depth: 35
Handling Equipment:
gantry shiploader, 54" conveyor
Cargo/Present Uses: Wet phosphate rock, diammonium phosphate, phos aci
Coast: g Load Rate: 3000 tph

Port: Tampa Ref #: 23 Tide: 1
Length: 1460 Depth: 34
Handling Equipment:
aveling gantry shiploader, 54" marginal belt
argo/Present Uses: Phosphate prods
Coast: g Load Rate: 3000 tph

3/09/94

DOCKING SPACE WITH PORT FACILITIES

ort: Tampa Ref #: 34 Tide: 1
ngth: 1200 Depth: 34
ndling Equipment:
orklift trucks, portable conveyors, covered truck loading shed
argo/Present Uses: Conventional/containerized, refrigerated, bananas
oast: g Load Rate: nl

ort: Tampa Ref #: 52 Tide: 1
ength: 1210 Depth: 32
Handling Equipment:
shiploading tower, 36" conveyor, fork lift trucks
Cargo/Present Uses: Steel prods, general cargo, citrus pellets, silica
Coast: g Load Rate: nl

Port: Tampa Ref #: 63 Tide: 1
Length: 1200 Depth: 34
Handling Equipment:
60- 2 to 25T fork lift trucks, additional furnished as required
Cargo/Present Uses: Conventional/containerized cargo
Coast: g Load Rate: nl

Port: Panama City (St Joe) Ref #: 3 Tide: 2
Length: 1500 Depth: 29
Handling Equipment:
Mobile crane with adjustable boom for handling hose, other cranes avai
Cargo/Present Uses: Soda ash, salt cake, caustic soda, fueloil, paper
Coast: g Load Rate: nl

ort: Panama City Ref #: 52 Tide: 2
Length: 1100 Depth: 32
Handling Equipment:
Barge loading spout, 24" conveyor, 3 steel tanks, lift trucks
Cargo/Present Uses: general cargo, paper prods, peanuts, drilling mud
Coast: g Load Rate: nl

Port: Panama City Ref #: 53 Tide: 2
Length: 1028 Depth: 32
Handling Equipment:
6- 3.5T paper roll clamp lift, forklifts, 35T crawler, 70T mobile cran
Cargo/Present Uses: General cargo
Coast: g Load Rate: nl

Port: Pascagoula Ref #: 69 Tide: 2
Length: 2900 Depth: 35
Handling Equipment:
3 revolving cranes, 5 additional gantry cranes
Cargo/Present Uses: Mooring vessels, scrap metal, steel plates by barg
Coast: g Load Rate: nl

Port: Pascagoula Ref #: 70 Tide: 2
Length: 3100 Depth: 35
Handling Equipment:
- revolving gantry cranes, 8 additional cranes available at shipyard
rgo/Present Uses: Mooring vessels, mooring floating drydock
Coast: g Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: Gulfport Ref #: 4 Tide: 2
ngth: 940 Depth: 30
ndling Equipment:
As required
Cargo/Present Uses: Conventional general cargo, paper, fert, fruits
Coast: g Load Rate: nl

Port: Gulfport Ref #: 8 Tide: 2
Length: 1850 Depth: 30
Handling Equipment:
As required
Cargo/Present Uses: General conventional cargo, foodstuffs
Coast: g Load Rate: nl

Port: Galveston Ref #: 24 Tide: 2
Length: 1486 Depth: 31
Handling Equipment:
4-60T gantry cranes, 2 straddle stkrs, 40T lift trks, grain gallery,
Cargo/Present Uses: Grain, conventional
Coast: g Load Rate: 50000 bus/hr

Port: Galveston Ref #: 25 Tide: 2
Length: 1185 Depth: 35
Handling Equipment:
4-60T gantry cranes, 2 straddle stkrs, 40T lift trks, grain gallery,
Cargo/Present Uses: Grain, conventional
Coast: g Load Rate: 80000 bus/hr

Port: Galveston Ref #: 28 Tide: 2
Length: 1205 Depth: 30
Handling Equipment:
4- 60T gantry cranes, 2 straddle stkrs, 40T lift trucks
Cargo/Present Uses: Conventional general cargo
Coast: g Load Rate: nl

Port: Galveston Ref #: 29 Tide: 2
Length: 1163 Depth: 30
Handling Equipment:
4- 60T gantry cranes, 2 straddle stkrs, 40T lift trucks
Cargo/Present Uses: Conventional general cargo, containerized
Coast: g Load Rate: nl

Port: Galveston Ref #: 30 Tide: 2
Length: 1173 Depth: 32
Handling Equipment:
4- 60T gantry cranes, 2 straddle stkrs, 40T lift trucks
Cargo/Present Uses: Sacked rice
Coast: g Load Rate: nl

Port: Galveston Ref #: 31 Tide: 2
Length: 1195 Depth: 33
Handling Equipment:
60T gantry cranes, 2 straddle stkrs, 40T lift trucks, 5-platforms
rgo/Present Uses: Conventional general cargo
Coast: g Load Rate: nl

Port: Galveston Ref #: 55 Tide: 2
ngth: 1040 Depth: 30
ndling Equipment:
1 gantry crane, 2 wingwall cranes, 4 mobile cranes, 50T straddle carri
Cargo/Present Uses: Mooring vessels for outfitting, repair, drydock
Coast: g Load Rate: nl

Port: Galveston Ref #: 57 Tide: 2
Length: 1158 Depth: 32
Handling Equipment:
1 gantry crane, 2 wingwall cranes, 4 mobile cranes, strad carr, addit
Cargo/Present Uses: Mooring vessels for outfitting, repair, drydock
Coast: g Load Rate: nl

Port: Freeport Ref #: 65 Tide: 2
Length: 1250 Depth: 30
Handling Equipment:
40T lift truck, 16 fork lift, portable pumps, hose, p. lines, float cr
Cargo/Present Uses: General cargo, misc. liquid, dry bulk commodities
Coast: g Load Rate: nl

Port: Brownsville et al Ref #: 291 Tide: 2
Length: 1000 Depth: 29
Handling Equipment:
As required
Cargo/Present Uses: General cargo
Coast: g Load Rate: nl

Port: Brownsville et al Ref #: 293 Tide: 2
Length: 1250 Depth: 32
Handling Equipment:
As required
Cargo/Present Uses: Ores, bulk materials
Coast: g Load Rate: nl

Port: Brownsville et al Ref #: 299 Tide: 2
Length: 1120 Depth: 28
Handling Equipment:
As required
Cargo/Present Uses: Steel, misc ores, scrap metal, bulk sodium sulphat
Coast: g Load Rate: nl

Port: Portland Ref #: 18 Tide: 8
Length: 938 Depth: 37
Handling Equipment:
4- mast & boom derricks, hose handling boom
Cargo/Present Uses: Petroleum prods
Coast: w Load Rate: nl

Port: Portland Ref #: 24 Tide: 8
Length: 1100 Depth: 34
Handling Equipment:
5T, 40T gantry cranes, 4 mobile cranes (45, 25, 18, 18T)
argo/Present Uses: Mooring vessels for outfitting & repair
Coast: w Load Rate: nl

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: Portland Ref #: 25 Tide: 8
ngth: 1250 Depth: 35
ndling Equipment:
15.5T, 6- 3.4T freight elevators, automated transfer system, forklifts
Cargo/Present Uses: General cargo
Coast: w Load Rate: nl

Port: Portland Ref #: 28 Tide: 8
Length: 1342 Depth: 40
Handling Equipment:
53T, 40T container handling cranes, 40T cont. top loader, additional
Cargo/Present Uses: Conventional/containeried, roll-on/roll-off,refrig
Coast: w Load Rate: 40cont/hr ea

Port: Portland Ref #: 29 Tide: 8
Length: 1200 Depth: 35
Handling Equipment:
4- gantry cranes, 5T mobile crane (gantry cranes for sale)
Cargo/Present Uses: Mooring vessels
Coast: w Load Rate: nl

Port: Portland Ref #: 30 Tide: 8
Length: 1100 Depth: 35
Handling Equipment:
10T mobile crane, 6 forklifts, 165 T mobile crane, 75T revolv float cr
Cargo/Present Uses: Conventional/containerized, refrigerated, steel
Coast: w Load Rate: nl

Port: Portland Ref #: 32 Tide: 8
Length: 1170 Depth: 35
Handling Equipment:
10T mobile crane, 6 forklifts, 165 T mobile crane, 75Trev cr, 150T drk
Cargo/Present Uses: Conventional/containerized, heavy lift
Coast: w Load Rate: nl

Port: Portland Ref #: 34 Tide: 8
Length: 1700 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Mooring excursion, trnsient, and display vessels
Coast: w Load Rate: nl

Port: Portland Ref #: 57 Tide: 8
Length: 3000 Depth: 40
Handling Equipment:
5- gantry cranes, 1- 20T revolving gantry crane
Cargo/Present Uses: Mooring vessels, mooring floating drydock
Coast: w Load Rate: nl

Port: Portland Ref #: 73 Tide: 8
Length: 944 Depth: 40
Handling Equipment:
T revolv gantry crane travels full length of wharf
rgo/Present Uses: Steel prods

Coast: w Load Rate: nl

Port: Portland Ref #: 74 Tide: 8
ngth: 900 Depth: 35
.ndling Equipment:
Fixed loading tower w/ telescoping vessel loading spout
Cargo/Present Uses: Dry bulk, bentonite, clay, talc, soda ash
Coast: w Load Rate: 300 tph

Port: Portland Ref #: 75 Tide: 8
Length: 1140 Depth: 40
Handling Equipment:
Tower crane, 2- 96" conveyors, 2-36T gantry cranes
Cargo/Present Uses: General cargo, dry bulk, alumina, pencil pitch
Coast: w Load Rate: 900 tph

Port: Portland Ref #: 77 Tide: 8
Length: 1500 Depth: 35
Handling Equipment:
35.5T container-handling crane, other container handling by request
Cargo/Present Uses: Conventional/containerized, molasses, tallow
Coast: w Load Rate: 40 cont/hr

Port: Portland Ref #: 78 Tide: 8
Length: 1500 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Roll-on/roll-off general cargo
Coast: w Load Rate: nl

Port: Portland Ref #: 79 Tide: 8
Length: 1500 Depth: 35
Handling Equipment:
Steel tower, 42" conveyor
Cargo/Present Uses: General cargo, grain
Coast: w Load Rate: 30,000 bu/hr

Port: Portland Ref #: 92 Tide: 8
Length: 2850 Depth: 40
Handling Equipment:
55T, 2- 50T, 2- 40T container handling cranes, 8- 45T straddle carrier
Cargo/Present Uses: Containerized general cargo, heavy lift items
Coast: w Load Rate: 40 cont/hr

Port: San Francisco Ref #: 8 Tide:
Length: 1200 Depth: 35
Handling Equipment:
6- mast & boom derricks
Cargo/Present Uses: Seafood, mooring & icing fishing vessels
Coast: w Load Rate: nl

Port: San Francisco Ref #: 9 Tide:
Length: 1314 Depth: 35
Handling Equipment:
ne
rgo/Present Uses: Mooring submarine on exhibition, transient vessels
Coast: w Load Rate: nl

Port: San Francisco Ref #: 17 Tide:
ngth: 1358 Depth: 35
ndling Equipment:
Vacuum lift for newsprint, company owned equip
Cargo/Present Uses: Newsprint
Coast: w Load Rate: nl

Port: San Francisco Ref #: 33 Tide:
Length: 1037 Depth: 35
Handling Equipment:
Unused traveling cargo platforms
Cargo/Present Uses: Mooring vessels, tugboats, small craft
Coast: w Load Rate: nl

Port: San Francisco Ref #: 35 Tide:
Length: 1000 Depth: 45
Handling Equipment:
90T mobile crane, 2- 18T mobile cranes, 12 forklift trucks
Cargo/Present Uses: Conventional/containerized, refrigerated, cocoa
Coast: w Load Rate: nl

Port: San Francisco Ref #: 42 Tide:
Length: 1300 Depth: 35
Handling Equipment:
2- mast & boom derrick, booms for handling hose
Cargo/Present Uses: Automobiles, fuel oil
Coast: w Load Rate: nl

ort: San Francisco Ref #: 43 Tide:
Length: 1138 Depth: 40
Handling Equipment:
4- container handling cranes, 1- 80T mobile crane, toplift/forklifts
Cargo/Present Uses: Conventional/containerized, roll-on/off, heavy lif
Coast: w Load Rate: nl

Port: San Francisco Ref #: 48 Tide:
Length: 2456 Depth: 40
Handling Equipment:
4- container handling cranes, 80T mobile crane, forklift/top lift truc
Cargo/Present Uses: Conventional/containerized, roll-on/off, heavy lif
Coast: w Load Rate: 25 cont/hr

Port: San Diego Ref #: 33 Tide: 4
Length: 1000 Depth: 35
Handling Equipment:
None
Cargo/Present Uses: Cruise ship passenger terminal, exhibition vess
Coast: w Load Rate: nl

Port: San Diego Ref #: 48 Tide: 4
Length: 1120 Depth: 27
Handling Equipment:
vailable as required
rgo/Present Uses: Conventional/containerized, bunkering vessels
Coast: w Load Rate: nl

8/09/94

DOCKING SPACE WITH PORT FACILITIES

ort: San Diego Ref #: 49 Tide: 4
ngth: 2580 Depth: 35
ndling Equipment:
0T receiving hopper, 12" pneumatic pipeline, additional as required
argo/Present Uses: Conventional/containerized, bunkering vess, cement
oast: w Load Rate: nl

Port: San Diego Ref #: 50 Tide: 4
Length: 920 Depth: 35
Handling Equipment:
Bulk shiploader, 42" conveyor, grain elevator
Cargo/Present Uses: Dry bulk commodoties, grain, potash, automobiles
Coast: w Load Rate: 700-1200 tph

Port: San Diego Ref #: 74 Tide: 4
Length: 910 Depth: 30
Handling Equipment:
60T, 35T gantry cranes, 16 mobile cranes (7 to 140T), 150T floating
Cargo/Present Uses: Mooring vessels for outfitting, repair, conversion
Coast: w Load Rate: nl

Port: Bellingham, WA Ref #: 7 Tide: 5
Length: 1365 Depth: 31
Handling Equipment:
30T, 35T log stackers, 14 forklift trucks, 36" conveyor
Cargo/Present Uses: General cargo, salt, lumber, logs, mooring tugs
Coast: w Load Rate: 700 tph

ort: Seattle Ref #: 1 Tide:
Length: 1875 Depth: 35
Handling Equipment:
As required
Cargo/Present Uses: Fruit, froen seafook, waste oil, automobiles
Coast: w Load Rate: nl

Port: Seattle Ref #: 2 Tide:
Length: 2222 Depth: 35
Handling Equipment:
As required
Cargo/Present Uses: Fruit, general cargo, mooring
Coast: w Load Rate: nl

Port: Seattle Ref #: 18 Tide:
Length: 1050 Depth: 35
Handling Equipment:
.5T mast & boom derrick, rental equipment available
Cargo/Present Uses: Mooring Coast Guard Vessels
Coast: w Load Rate: nl

Port: Seattle Ref #: 21 Tide:
Length: 1852 Depth: 40
Handling Equipment:
0T container handling cranes
rgo/Present Uses: Containerized general cargo
Coast: w Load Rate: 20 cont/hr e

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: Seattle Ref #: 22 Tide:
ngth: 1580 Depth: 50
ndling Equipment:
3- 40T container handling cranes, 2-30T, 2- 10T, 2- 3T lift trucks
Cargo/Present Uses: Containerized general cargo
Coast: w Load Rate: 20 cont/hr e

Port: Seattle Ref #: 32 Tide:
Length: 968 Depth: 45
Handling Equipment:
45T gantry crane, 15T, 35T mobile cranes, 11- forklifts, 150T gantry c
Cargo/Present Uses: Mooring vessels for outfitting & repair, drydock
Coast: w Load Rate: nl

Port: Seattle Ref #: 71 Tide:
Length: 1200 Depth: 40
Handling Equipment:
50T gantry crane, 25 forklift trucks
Cargo/Present Uses: Conventional general cargo, heavy lift
Coast: w Load Rate: nl

Port: Seattle Ref #: 75 Tide:
Length: 1162 Depth: 30
Handling Equipment:
Hammerhead crane, 36" stacker belt, 2- front end loaders
Cargo/Present Uses: Limestone, iron, slag, clay
Coast: w Load Rate: 1000 tph

ort: Seattle Ref #: 86 Tide:
Length: 2500 Depth: 40
Handling Equipment:
5- 50T, 40T container handling cranes, 8- container lift trucks
Cargo/Present Uses: Containerized general cargo
Coast: w Load Rate: >20 cont/hr

Port: Seattle Ref #: 219 Tide:
Length: 1056 Depth: 40
Handling Equipment:
6- hydraulic cranes for handling hose, stiff-leg derrick, forklifts
Cargo/Present Uses: Crude oil, petroleum prods, bunkering vess&barges
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 2 Tide: 4
Length: 1830 Depth: 35
Handling Equipment:
8- mast&boom hose handling derricks
Cargo/Present Uses: Petroleum prods, fueling US Govt vessels
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 6 Tide: 4
Length: 903 Depth: 51
Handling Equipment:
- 16" & 1- 12" swivel-jointed unloading arms mounted on steel structu
rgo/Present Uses: Crude oil, petroleum prods
Coast: w Load Rate: nl

8/09/94

DOCKING SPACE WITH PORT FACILITIES

ort: Los Angeles Ref #: 9 Tide: 4
ngth: 1500 Depth: 37
ndling Equipment:
5T, 20T crawler cranes
argo/Present Uses: Steel prods, scrap metal
oast: w Load Rate: nl

Port: Los Angeles Ref #: 10 Tide: 4
Length: 1400 Depth: 33
Handling Equipment:
Conventional general cargo
Cargo/Present Uses: As needed
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 13 Tide: 4
Length: 1880 Depth: 33
Handling Equipment:
None
Cargo/Present Uses: Mooring vessels
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 20 Tide: 4
Length: 1645 Depth: 30
Handling Equipment:
None
Cargo/Present Uses: Mooring fishing boats, handling provisions
oast: w Load Rate: nl

Port: Los Angeles Ref #: 44 Tide: 4
Length: 1037 Depth: 45
Handling Equipment:
4- 40T container handling cranes
Cargo/Present Uses: Containerized general cargo
Coast: w Load Rate: 20 cont/hr

Port: Los Angeles Ref #: 45 Tide: 4
Length: 1000 Depth: 35
Handling Equipment:
40T container handling crane, 40T portal cont hand, 6- bridge cranes
Cargo/Present Uses: Containerized general cargo
Coast: w Load Rate: 35-70 cont/h

Port: Los Angeles Ref #: 46 Tide: 4
Length: 1030 Depth: 35
Handling Equipment:
40T container handling crane, straddle carrier, container lift truck
Cargo/Present Uses: Not used
Coast: w Load Rate: 35 cont/hr

Port: Los Angeles Ref #: 49 Tide: 4
Length: 2415 Depth: 35
Handling Equipment:
ailable as needed
argo/Present Uses: Conventional/containerized, roll-on/off, steel
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 54 Tide: 4
ngth: 1766 Depth: 35
ndling Equipment:
2- gantry adjustable platforms, electric cargo elevator, passeng eleva
Cargo/Present Uses: Conventional/containerized cargo, passengers
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 60 Tide: 4
Length: 1250 Depth: 35
Handling Equipment:
5- 1T mast&boom derricks for handling hose
Cargo/Present Uses: Petroleum prods
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 78 Tide: 4
Length: 1559 Depth: 35
Handling Equipment:
13- cargo ramps, 5- portable conveyors, escalators, forklift trucks
Cargo/Present Uses: Conventional/containerized general cargo, passenge
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 82 Tide: 4
Length: 2185 Depth: 45
Handling Equipment:
4- container handling cranes, 4- container bridges, 12 straddle carrie
Cargo/Present Uses: Containerized, roll-on/off, conventional general
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 89 Tide: 4
Length: 913 Depth: 45
Handling Equipment:
3- 40T container handling cranes, 2- 30T mobile cranes, stradle carrie
Cargo/Present Uses: Containerized general, petroleum prods, petrochems
Coast: w Load Rate: 35 cont/hr

Port: Los Angeles Ref #: 90 Tide: 4
Length: 3569 Depth: 35
Handling Equipment:
3- 40T container handling cranes, 2- 30T mobile cranes, stradle carrie
Cargo/Present Uses: Containerized general, petroleum prods, petrochems
Coast: w Load Rate: 35 cont/hr

Port: Los Angeles Ref #: 93 Tide: 4
Length: 1089 Depth: 45
Handling Equipment:
35T gantry crane
Cargo/Present Uses: Containerized general, lumber, steel, cotton, auto
Coast: w Load Rate: nl

Port: Los Angeles Ref #: 94 Tide: 4
Length: 1270 Depth: 45
Handling Equipment:
- 40T, 1- 30T container handling cranes, 2- 20T straddle carriers
argo/Present Uses: Containeried general cargo
Coast: w Load Rate: 40 cont/hr

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: Los Angeles Ref #: 95 Tide: 4
ngth: 920 Depth: 45
ndling Equipment:
2- 40T container handling cranes, 3- 40T straddle carriers, 35T frklft
Cargo/Present Uses: Conventional/containerized
Coast: w Load Rate: 35 cont/hr

Port: Los Angeles Ref #: 96 Tide: 4
Length: 1436 Depth: 45
Handling Equipment:
2- 40T container handling cranes, 1- 40T, 2- 30T straddle carriers
Cargo/Present Uses: Containerized general cargo
Coast: w Load Rate: 35 cont/hr

Port: Los Angeles Ref #: 99 Tide: 4
Length: 1809 Depth: 32
Handling Equipment:
3- 22T gantry cranes, 2- 30T locomotive cranes
Cargo/Present Uses: Mooring vessels for outfitting & repair
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 3 Tide: 4
Length: 2100 Depth: 36
Handling Equipment:
3- 40T container handling cranes, 2- 40T, 3- 30T mobile cranes
Cargo/Present Uses: Conventional/containerized, bunkering vessels
Coast: w Load Rate: 25-30 cont/h

Port: Long Beach, CA Ref #: 4 Tide: 4
Length: 1200 Depth: 39
Handling Equipment:
2- 40T container handling cranes, 7- 30T mobile container bridge crane
Cargo/Present Uses: Conventional/containerized, bunkering vessels
Coast: w Load Rate: 30-35 cont/h

Port: Long Beach, CA Ref #: 6 Tide: 4
Length: 2300 Depth: 36
Handling Equipment:
4- 30T container handling cranes, 6- 30T, 4- 40T container bridge cran
Cargo/Present Uses: Conventional/containerized, bunkering vessels
Coast: w Load Rate: 25-30 cont/h

Port: Long Beach, CA Ref #: 9 Tide: 4
Length: 1100 Depth: 43
Handling Equipment:
2- 30T container handling cranes
Cargo/Present Uses: Conventional/containerized, bunkering vessels
Coast: w Load Rate: 25-30 cont/h

Port: Long Beach, CA Ref #: 13 Tide: 4
Length: 1910 Depth: 35
Handling Equipment:
- bulk shiploaders, 60" conveyor, telescoping loading spouts
argo/Present Uses: Shipment of iron ore, iron ore pellets, potash
Coast: w Load Rate: 2500-5000tph

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: Long Beach, CA Ref #: 19 Tide: 4
ngth: 1200 Depth: 31
ndling Equipment:
6- mobile cranes up to 150T capacity
Cargo/Present Uses: Conventional, steel, steel prods, lumber, mooring
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 20 Tide: 4
Length: 1275 Depth: 34
Handling Equipment:
6- mobile cranes up to 150T capacity
Cargo/Present Uses: Conventional, steel, steel prods, lumber, mooring
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 26 Tide: 4
Length: 2917 Depth: 27
Handling Equipment:
Available as required
Cargo/Present Uses: Conventional general, citrus fruits, grapes
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 28 Tide: 4
Length: 1270 Depth: 32
Handling Equipment:
Available as required
Cargo/Present Uses: Conventional general cargo
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 30 Tide: 4
Length: 1200 Depth: 32
Handling Equipment:
None
Cargo/Present Uses: Roll-on/off cargo containers
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 32 Tide: 4
Length: 1994 Depth: 30
Handling Equipment:
Available as required
Cargo/Present Uses: Conventional general cargo
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 34 Tide: 4
Length: 1942 Depth: 35
Handling Equipment:
4- 40T container handling cranes, 6- 40T mobile straddle carriers
Cargo/Present Uses: Containerized, roll-on/off
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 36 Tide: 4
Length: 1984 Depth: 40
Handling Equipment:
xed bulk loading tower w/ telescop gravity spout, belt conveyor sys
rgo/Present Uses: Misc dry bulk, coke, salt dake, soda ash, potash
Coast: w Load Rate: 500-800 lt/h

8/09/94 DOCKING SPACE WITH PORT FACILITIES

Port: Long Beach, CA Ref #: 38 Tide: 4
ngth: 1607 Depth: 33
ndling Equipment:
Traveling steel frame supports vertical screw conveyor, 48" conveyor
Cargo/Present Uses: Bulk cement, steel, animal fats, vegetable oil
Coast: w Load Rate: 500 lt/hr

Port: Long Beach, CA Ref #: 61 Tide: 4
Length: 1100 Depth: 30
Handling Equipment:
Receiving hopper, 36" conveyor, storage building
Cargo/Present Uses: Gypsum rock by self-unloading ves, petroleum, auto
Coast: w Load Rate: nl

Port: Long Beach, CA Ref #: 62 Tide: 4
Length: 1972 Depth: 48
Handling Equipment:
2- 12" loading arms, 5- 10", 4- 8" loading arms
Cargo/Present Uses: Crude oil, petroleum prods, bunkering
Coast: w Load Rate: nl

Port: Port Hueneme, CA Ref #: 4 Tide: 4
Length: 1800 Depth: 35
Handling Equipment:
4- 14" belt conveyors, additional available as required
Cargo/Present Uses: Conventional gen, bagged fert, bananas, wood, lumb
Coast: w Load Rate: 3000 bx/hr

Port: Port Hueneme, CA Ref #: 8 Tide: 4
Length: 1025 Depth: 35
Handling Equipment:
Available as required
Cargo/Present Uses: Conventional gen, mooring & fueling naval vessels
Coast: w Load Rate: nl

Port: Port Hueneme, CA Ref #: 12 Tide: 4
Length: 1202 Depth: 35
Handling Equipment:
Available as required
Cargo/Present Uses: Conventional gen, mooring & fueling naval vessels
Coast: w Load Rate: nl

Port: Anchorage AK Ref #: 1 Tide: 25
Length: 1508 Depth: 35
Handling Equipment:
2- 27.5T Container handling cranes, 3- gantry cranes, addit. upto 150T
Cargo/Present Uses: Containerized, roll-on/off general cargo
Coast: w Load Rate: 32 cont/hr

Port: Whittier, AK Ref #: 35 Tide: 11
Length: 1000 Depth: 30
Handling Equipment:
T crawler crane, 30T mobile crane
rgo/Present Uses: Fish, mooring fishing boats, misc vessels
Coast: w Load Rate: nl

8/09/94

DOCKING SPACE WITH PORT FACILITIES

Port: Kodiak, AK Ref #: 1 Tide: 9
ngth: 1590 Depth: 27
.ndling Equipment:
None
Cargo/Present Uses: mooring misc vessels, poor condition at time surve
Coast: w Load Rate: nl

Appendix E

Pathways for the Disposal of Municipal Incinerator Fly Ash, Contaminated Dredged Material, and Sewage Sludge

Appendix F

Trip Report on 15th Annual Meeting and Technical Conference of the Western Dredging Association and the 27th Annual Texas A&M Dredging Seminar

TRIP REPORT

BY
MICHAEL HIGHTOWER
OCEANEERING TECHNOLOGIES, INC.

FOR ATTENDING:

WEDA XV

FIFTEENTH ANNUAL MEETING AND
TECHNICAL CONFERENCE
OF THE
WESTERN DREDGING ASSOCIATION
AND THE
TWENTY SEVENTH ANNUAL
TEXAS A&M DREDGING SEMINAR

MAY 18-20, 1994
SAN DIEGO, CA

The Western Dredging Association's annual meeting (WEDA XV) and Texas A&M's annual dredging seminar were jointly held in San Diego on May 18-20. The following literature from the conference is included as attachments to this report:

- Program agenda for the three day conference
- Abstracts of the papers from the Texas A&M dredging conference
- Publications list from the COASTAL ENGINEERING LABORATORY, Department of Civil Engineering, Texas A&M University
- Call for Papers for FOURTEENTH WORLD DREDGING CONGRESS
- Pamphlet on DREDGING '94, The Second International Conference on Dredging and Dredged Material Placement
- Interagency Working Group on the Dredge Process - Options Paper

Unfortunately, the proceedings of the conference papers have not been published; they are expected out in the next couple of months. In lieu of submitting the proceedings, summaries of key papers applicable to the APWI project are included below.

Modeling Dredged Material Placement at Baldhead Shoals Disposal Site - H.R. Moritz and R.E. Randall, Ocean/Civil Engineering, Texas A&M University, College Station, TX

Dr. Randall presented a paper on a computer model developed to predict the dredge material mound profile generated by repeated surface disposal operations. This model was validated via actual disposal operations at the Baldhead Shoals Disposal Site. This model is being co-developed by Texas A&M and the USAE Waterways Experiment Station (WES). This model combines two earlier models already developed to predict short term and long term effects of surface disposal.

The short term model is called Short Term Fate (STFATE) and is used to predict the fate of a single disposal operation. This model is used for transient prediction of the mound from the time the dump scow is opened until the material settles over the next couple of hours. This model was developed by Dr. Billy Johnson, WES.

The long term model is called Long Term Fate (LTFATE) and is used to predict the dispersion of a mound over a long period.

The new model being developed is called ODAMS, which combines short term and long term modeling to predict the mound size and shape from repeated disposal operations. The model was validated by entering exact disposal sites/loads for 869 disposal operations for a total of 2.4 million cubic yards. The results are as follows:

Mound Characteristic	Model Prediction	Actual Measurement
Height	13.5 ft.	15.6 ft.
Diameter	1900 ft.	2000 ft.

As stated by Dr. Randall, the simulation is useful for managing open water disposal sites. Other uses are:

- Capping contaminated sediments
- Pipeline burial
- Sizing disposal sites

The computer simulation is in the final development stage. It is scheduled to be released to the public in October 1994 by WES. The name is planned to be changed from ODAMS to Multiple Deposit Fate (MDFATE).

Related to APWI, this simulation could be used to model the mound profile for several of the engineering disposal concepts. Specifically, the submerged barge disposal without bags is nearly the same as surface disposal in shallow water. OTECH will follow up with WES regarding the early availability of using this model and the applicability of using it for continuous stream modeling, i.e. the pipe riser system.

Options for Submerged Discharge of Dredge Material - Dr. Michael R. Palermo, U.S. Army Corps of Engineers Experiment Station, Vicksburg, MS

Dr. Palermo presented a paper on the use of a submerged pipe as a means of discharging dredged material. Submerged discharge is primarily used in conjunction with hydraulic dredging where the material has very low solids content, and thus can be piped from the source to the disposal area. At the end of the vertical pipe a diffuser is mounted to slow down the discharge velocity as the material impacts the bottom. The objective is to minimize the benthic impact. The design of the diffuser theoretically reduces the velocity by a 16:1 ratio.

WES had a model diffuser built and tested. A velocity reduction of 6:1 was measured. The decrease in efficiency from theoretical to measured was attributed to manufacturing short cuts. The fabricator welded short straight sections to approximate a parabolic shape rather than form the continuous curve per the specification.

Pipes with diffusers have been used in practice in the Chesapeake Bay and in the Chicago area.

The applicability to APWI is via the pipe riser concept. By mounting a diffuser on the end of the pipe, the waste stream velocity is decreased which will minimize bottom impact, and hence, plume generation. Design information is being sent to OTECH.

Cable Arm Environmental Dredging at Pickering Nuclear Generating Station - Deborah A. Hempel, Ontario Hydro, Toronto, Canada

Ms. Hempel presented a paper on the dredging and disposal of contaminated material at the Pickering Nuclear Power Plant. The unique feature of this operation was the use of a mechanical dredging bucket called a cable arm dredge. This device has unique design features, such as a sealing system, which minimizes the turbidity when dredging. It also has air operated vents which allow water to overflow maximizing the solids content.

The cable arm dredge bucket typically has a slower cycle time, but other design features, such as a level cut, provide equivalent production rates when compared with a standard clamshell bucket.

The approximate cost for removal and hauling of this contaminated sediment was $150/ton. The sediment was stored locally in a lined sediment pit.

The high solids content feature of this device makes it applicable to the APWI project. This device could be used during the dredging process to deliver high solids content material directly for disposal. It also could be used at a port for loading high solids waste streams onto the transport vessels.

A Case Study for Removing Contaminated Sediments in Toronto Harbour
- Ian Orchard, Environmental Protection, Ontario, Canada

For this operation, a cable arm mechanical dredging bucket was used. Sediment was then transferred to a treatment site via truck.

Environmental Protection of Canada, analogous to our EPA, has a database of 60 technologies of treatment, of which 16 have been demonstrated to some degree.

The approximate costs for remediation were given:

$350/ton for total remediation
$70 - $100 / ton for bioremediation
$50 - $70 / ton for metals removal

No single treatment has been found which can remove organics and biologicals.

Appendix G

FMECA Results

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Surface Emplacement
Component/Subsystem: Flexible Bladder

Function: Store waste stream products during transport to APWI sea floor disposal site and provide containment following emplacement

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Rupture	1) Manufacturing Defect	1) Waste stream product spill leading to:	1) QA program	C	III	Vendor certification; Qualification tests
	2) Over pressure during filling operation	- Contamination of barge, water surface and intervening water column	2) Automatic system with sensor redundancy	C	III	
	3) Damaged during release or loading	2) Potential explosion in presence of spark (for sewage sludge only)		C	III	
2) Incorrect scatter pattern	1) Free-fall Hydrodynamics imperfect between successive bladder releases	1) Sealed or potentially leaking flexible bladders emplaced out of disposal site boundary	1) Characterization tests 2) Procurement specifications and QA inspection	C	IV	Good quality assurance program should minimize probability of occurrence; If emplaced off-site, flexible bladders should remain sealed.
	2) Fluctuations in current profile vs depth during emplacement operations		3) Flexible bladders could be instrumented to locate each's emplacement 4) Verify current profile & emplacement accuracy prior to bulk cargo release	C	IV	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Surface Emplacement
Component/Subsystem: Navigation Equipment

Function: Position barge over approved emplacement area.

Failure Mode	**Failure Causes and Mechanisms**	**Failure Effects**	**Failure Detection Method**	**PO**	**SC**	**Failure Prevention and Compensating Features**
Barge emplace load at wrong location (not in approved area)	1) GPS or related processing or display equipment/software. 2) Human Error	Emplacement in unauthorized area non-compliant with disposal site permit.	Approved site with: a) Transponder beacons b) Bottom mounted micro-transponders with each load increment to determine emplacement position $\pm$ 5m	D C	IV IV	1) GPS systems are mature , simple, and inherently reliable. 2) Could be made redundant 3) TUG should have additional navigation equipment 4) Approved site area should have permanent "markers" 5) JASON or ARGO system using bottom mounted transponders as back-up to GPS

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Surface Emplacement
Component/Subsystem: Trap Door Mechanism
Function: Release flexible bladders on command

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Fail to release flexible bladder	1) "n of m" release mechanism failures	1) Potential damage (puncture) of partially released bladder	BITE for triggering circuitry	C	IV	Extensive BITE for test of power system.
	2) Power source (battery or wiring)			C	IV	
	3) Trigger/logic circuitry failure			C	IV	
	4) Human error in enabling triggering circuitry or verifying power status			C	IV	
2) Premature release of flexible bladder(s)	1) Sneak circuit	1) Emplacement off site	Use PAL sequencing to enable/arm & trigger operation	D	III	Sludge/waste contained in flexible bladder preventing contamination of incorrect emplacement site.
	2) Trigger circuitry failure			D	III	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Surface Emplacement
Component/Subsystem: Electrical Power

Function: Power Trap Door release circuitry and barge position location sensors

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) No or inadequate power	1) Discharged batteries	1) Cannot release flexible bladders	BITE & PM/FL Instrumentation	D	IV	1) Return to port 2) Power system redundancy
	2) Sea Water short			D	IV	
	3) Defective wiring/or umbilical connection to host vessel			D	IV	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Navigation Equipment

Function: Position barge over approved emplacement area.

Failure Mode	**Failure Causes and Mechanisms**	**Failure Effects**	**Failure Detection Method**	**PO**	**SC**	**Failure Prevention and Compensating Features**
Barge emplaces load at wrong location (not in approved area)	1) GPS or related processing or display equipment/software. 2) Human Error	Emplacement in unauthorized area non-compliant with disposal site permit	Approved site with: a) Transponder beacons b) Disposable transponders with each load to determine emplacement $\pm$ 5M	D C	IV IV	1) GPS systems are mature , simple, and inherently reliable. 2) Could be made redundant 3) TUG should have additional navigation equipment 4) Approved site area should have permanent "markers"

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Trap Door Mechanism

Function: Release flexible bladders on command

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Fail to release flexible bladder	1) "n of m" Actuator Failures	1) Potential loss of Glider	Built-In-Test-Equipment (BITE) for triggering circuitry	D	I	1) Triple redundancy
	2) Power source (battery or wiring)	2) Potential damage (puncture) of partially released bladder		D	I	2) NDT of all transponder mechanisms
	3) Trigger/logic circuitry failure			D	I	3) Extensive BITE for power system.
	4) Human error in enabling triggering circuitry or verifying power status			D	I	
2) Premature release of flexible bladder(s)	1) Sneak circuit	1) Emplacement off site	Use Permissive Action Linkage (PAL) sequencing to enable/arm & Trigger	D	III	Waste Stream Product contained in flexible bladder preventing contamination of incorrect emplacement site.
	2) Trigger circuitry failure			D	III	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Hull Structure

Function: 1) Pressure Hull: Protect electronics
2) External Structure: Exostructure and Component foundation

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Pressure Hull Failure	1) Damage due to handling or collision	1) Loss of onboard electronics including navigation circuitry; Potential loss of vehicle	Not detectable in time	D	I	Design margin; in port inspection prior to departure.
2) External Structure Failure	1) Damage due to handling or collision	1) Jamming of elavons' mechanism 2) Damage of Flexible Bladders 3) Inability to emplace flexible bladders potentially leading to mission cancellation or loss of Glider if undetected. Glider would not be launched if it had been involved in an at-sea collision; Prelaunch systems check would confirm cargo release system function.		C	II	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider Vessel
Component/Subsystem: Electrical Power

Function: Provide/Distribute electrical power for Glider operation

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) No or inadequate main power	1) Discharged batteries	1) Failure to release many flexible bladders which could prevent glider from being re-acquired	Extensive testing prior to release of barge for emplacement	D	I	Independent power subsystem to be provided for critical loads
	2) Sea Water short			D	I	
	3) Defective wiring	2) Failure to power "location signals" preventing re-acquisition of glider		D	I	
2) Loss of emergency power	1) Discharged batteries	1) None unless main power is also lost. Then see above.		D	IV	This is back-up system. Same prevention as above
	2) Sea Water short			D	IV	
	3) Defective wiring			D	IV	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Location Signaling

Function: 1) Assist in re-acquiring Glider
2) Collision avoidance

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Running light system failure	1) Component failure	1) Potential inability to locate glider following resurfacing	Visual inspection	D	II	1) Lighting system redundant 2) Audible bell or "Fog" horn can also be implemented
	2) Power Failure	2) Not seen by vessel leading to collision		D	II	3) Independent emergency power system provided 4) Pendant Buoy System provides early warning of gliders' resurfacing Note: Location can be determined by transportation tug radar, when present.

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Command, Communication, & Control

Function: 1) Cargo Control 2) Vessel Control 3) Communications

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Cargo Control Failure	1) Component failure (Sensors, mechanical and/or hydraulic actuators)	1) Inability to release flexible bladder(s) leading to potential loss of Glider 2) Premature release of cargo leading to slight deviation of emplacement location and/or impact on Glider trim and glide path	Pre-mission verification	D	I	Many failures would have to occur before impact was noticed
2) Loss of Glider Control	1) Sensor (pressure) failure 2) Pinger failure 3) Static Control 4) Elavons mechanism failure	1) Emplacement off-site; Resurface away from TUG 2) Glider could auger-into seabed if load release also fails		D D D D	III III III III	Extensive design analysis and pre-operational test program Component selection
3) Communication Failure	1) Real time communication failure 2) Data Logging failure	1) Potential loss of glider's location and inability to reacquire glider 2) Loss of emplacement records		D D	II IV	" " " "

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Hydraulic

Function: Provide hydraulic power for elavons' and door actuators

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Incorrect glide path	1) Component failure (reservoirs, compensators, pumps)	1) Emplacement off-site	Pre-mission check-out	D	III	1) Extensive design analysis and test program; Bladders contain waste if emplaced off-site
2) Inability to emplace flexible bladders	" "	1) Loss of glider	Pre-loading check-out	D	I	1) " " 2) Back-up release mechanism (e.g., explosive bolts, or slave mechanism actuated by load cells that have released.

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Mechanical Handling System

Function: Used for transportation, launch and recovery, and towing of vessel

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Pendant Buoy System Failure	1) Failure to operate (mechanical component) 2) Failure to release (electrical failure)	Does not provide early visual warning of imminent barge surfacing following dump run, prevents use of buoy & line to assist in remating	None	D D	IV IV	1) Glider running lights 2) Tug monitors ascent on sonar and can warn nearby shipping 3) Secondary recovery line used
2) Transport Interface System Failure	1) TUG Interface 2) Ballast system 3) Control/ Power Take-off 4) Pendant buoy recovery winch	1) Loss of glider during transport 2) Inability to launch glider 3) Inability to Pre-set control planes 4) Inability to winch glider back into carrier using pendant buoy wire.	Inspection	D D D D	II IV III IV	1) Preventive maintenance 2) Pre-mission, launch inspections
3) Cargo Loading/Handling Failure	1) Loading Hatch 2) Load Release Mechanism	1) Inability to adjust trim which would result in incorrect glide path; Mission aborted/delayed 2) Queuing failure	1) Pre-load check-out 2) Preventive maintenance	D D	IV IV	Repair prior to launch

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: ROV Glider
Component/Subsystem: Flexible Bladder

Function: Store waste stream products during transport to APWI sea floor disposal site and provide containment following emplacement

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Rupture	1) Manufacturing Defect 2) Over pressure during filling operation 3) Damaged during release or loading	1) Waste stream product spill leading to: - Contamination of barge, water surface and intervening water column 2) Potential explosion in presence of spark (for sewage sludge only)	1) QA program 2) Automatic system with sensor redundancy	C C C	III III III	Vendor certification; Qualification tests

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Navigation Equipment

Function: Position barge over approved emplacement area.

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
Barge emplaces load at wrong location (not in approved area)	1) GPS or related processing or display equipment/software. 2) Human Error	Emplacement in unauthorized area non-compliant with disposal site permit	Approved site with: a) Transponder beacons b) Disposable transponders with each load to determine emplacement $\pm$ 5M	D C	IV IV	1) GPS systems are mature, simple, and inherently reliable. 2) Could be made redundant 3) TUG should have additional navigation equipment 4) Approved site area should have permanent "markers"

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Trap Door Mechanism
Function: Release flexible bladders on command

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Fail to release flexible bladder	1) "n of m" Rotating Actuator Failures 2) Power source (battery or wiring) 3) Trigger/logic circuitry failure 4) Human error in enabling triggering circuitry or verifying power status	1) Potential loss of Disk if failure to release four or more flexible bladders (of total of 169) 2) Potential damage (puncture) of partially released bladder	Built-In-Test-Equipment (BITE) for triggering circuitry	D D D D	II II II II	1) Triple redundancy 2) NDT of all trapdoor mechanisms 3) Extensive BITE for power system.
2) Premature release of flexible bladder(s)	1) Sneak circuit 2) Trigger circuitry failure	1) Emplacement off site	Use Permissive Action Linkage (PAL) sequencing to enable/arm & Trigger	D D	III III	Waste Stream Product contained in flexible bladder preventing contamination of incorrect emplacement site.

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Hull Structure

Function: 1) Pressure Hull: Protect electronics
2) External Structure: Exostructure and Component foundation

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Pressure Hull Failure	1) Damage due to handling or collision	1) Loss of onboard electronics including navigation circuitry; Potential loss of Disk	Not detectable in time	D	II	Design margin; in port inspection prior to departure.
2) External Structure Failure	1) Damage due to handling or collision	1) Jamming of Control Surfaces 2) Damage of Flexible Bladders 3) Inability to emplace flexible bladders potentially leading to mission cancellation or loss of Disk if undetected. Disk would not be launched if it had been involved in an at-sea collision; Prelaunch systems check would confirm cargo release system function.		C	II	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Electrical Power

Function: Power Trap Door release circuitry and barge position location sensors

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) No or inadequate power during descent	1) Discharged batteries	1) Failure to release four or more flexible bladders which could prevent Disk from surfacing for recovery	Built-In-Test-Equipment (BITE) & Performance Monitoring/Fault Location (PM/FL) instrumentation	D	II	Power system redundancy.
	2) Sea Water short			D	II	
	3) Defective wiring			D	II	
2) Loss of emergency power	1) Discharged batteries	1) None, unless main power is also lost. Then see above.		D	IV	This is back-up system. Same prevention as above.
	2) Sea Water short			D	IV	
	3) Defective wiring			D	IV	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Location Signaling

Function: 1) Assist in re-acquiring Disk
2) Collision avoidance

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Running light system failure	1) Component failure	1) Potential inability to locate glider following resurfacing	Visual inspection	D	II	1) Lighting system redundant 2) Audible bell or "Fog" horn can also be implemented
	2) Power Failure	2) Not seen by vessel leading to collision		D	II	3) Independent emergency power system provided 4) Pendant Buoy System provides early warning of gliders' resurfacing Note: Location can be determined by transportation tug radar, when present.

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Component/Subsystem: Direct Descent Disk Command, Communication, & Control

Function: 1) Cargo Control 2) Vessel Control 3) Communications

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Cargo Control Failure	1) Component failure (Sensors, mechanical and/or hydraulic actuators)	1) Inability to release flexible bladder(s) leading to potential loss of Disk 2) Premature release of cargo leading to slight deviation of emplacement location and/or impact on Disk trim and glide path	Pre-mission verification	D	II	Many failures would have to occur before impact was noticed
2) Brake System Failure	1) Sensor (pressure) failure 2) Actuator failure 3) Control Surface 4) Power failure	1) Bags may not release; potential Disk loss 2) Partial actuations cause Disk to go unstable; potential Disk loss		D D D D	II II II II	Extensive design analysis and pre-operational test program Component selection
3) Communication Failure	1) Real time communication failure 2) Data Logging failure	1) Potential loss of glider's location and inability to reacquire glider 2) Loss of emplacement records		D D	II IV	" " " "

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Hydraulic
Function: Provide hydraulic power for brake system and door actuators

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Incorrect glide path	1) Component failure (reservoirs, compensators, pumps)	1) Emplacement off-site	Pre-mission check-out	D	III	1) Extensive design analysis and test program; Bladders contain waste if emplaced off-site
2) Inability to emplace flexible bladders	" "	1) Loss of Disk	Pre-loading check-out	D	II	1) " " 2) Back-up release mechanism (e.g., explosive bolts, or slave mechanism actuated by load cells that have released.

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Floater Module

Function: To house disk to/from APWI site

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Floater won't release Disk	1) Mechanical failure	Can't deploy Disk		C	IV	
	2) Power failure			C	IV	
2) Floater/Disk collision during recovery	1) Weather	Floater damage; could result in loss of Floater/personnel		D	I	
	2) Operator Error			C	I	
3) Floater unable to recouple to "Barge"	1) Locking device failure	Have to tow in		D	IV	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Direct Descent Disk
Component/Subsystem: Flexible Bladder

Function: Store waste stream products during transport to APWI sea floor disposal site and provide containment following emplacement

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Rupture	1) Manufacturing Defect 2) Over pressure during filling operation 3) Damaged during release or loading	1) Waste stream product spill leading to: - Contamination of barge, water surface and intervening water column 2) Potential explosion in presence of spark (for sewage sludge only)	1) QA program 2) Automatic system with sensor redundancy	C C C	III III III	Vendor certification; Qualification tests

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Transfer Line Assembly

Function: Transfer Waste Stream Product from Transport Vessel to Riser Pipe Platform

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Pipe Fracture	1) Cyclic Fatigue	1) Platform contamination leading to personnel and/or water contamination 2) Release of Methane Gas (Platform contamination only) which in the presence of a spark could lead to an explosion	1) Pressure, Flow Sensor 2) Visual Inspection 3) Odor (If sludge)	D	II	1) Pipe Design Margin 2) Pipe Material Selection
2) Pipe Burst	1) Over Pressure	1) Water contamination	" "	D	II	1) " "
3) Pipe Damage	1) Handling	1) Surface water contamination	" "	C	II	1) Piping Support /Motion Compensation
4) Stuck Valve	1) Component Failure	1) Inability to Transfer Waste and/or spill	1) Pressure or flow rate instrumentation	C	IV	1) Redundancy for "stuck closed", Manual over-ride for "Stuck open" Preventive Maintenance
5) Pumping Failure	1) Pump or Power Failure	1) Inability to transfer or maintain transfer rate of sludge	1) Status Indicators	C	IV	1) " "

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Riser Pipe

Function: Provide containment system for waste stream being transported from surface to Abyssal Plains

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Constricted/ Plugged	1) Diffusion construction due to Foreign Objects	1) Contamination of intervening water column combined with failure modes 2, 3, &4 2) Shut down pipe flow increasing external differential hydrostatic pressure 3) If specific gravity is in excess of control threshold, can generate excessive internal pressure	Pressure and/or flow sensors along pipe length	E	II	1) Full redundancy, with 4:1 operational stress/strain design margins 2) Tightly controlled and monitored specific gravity system 3) Pressure relief and check valves 4) Measurement of tension/stress of/on pipe
2) Fracture	1) Cyclic Fatigue 2) Stress on pipe from platform trim, drift, failed compensator subsystem, or bad weather	" "		E D	I I	" "

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Riser Pipe (Cont.)

Function: Provide containment system for waste stream being transported from surface to Abyssal Plains

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
3) Burst	1) Over pressure from incorrect flow rate, pumping system/sensor failure, high specific gravity	1) Contamination of intervening water column	Pressure and/or flow sensors along pipe length	D	I	1) Design margin 2) Tightly controlled and monitored slurry specific gravity system 3) Pressure relief and check valves located along length of riser pipe(s) 4) Measure tension/stress on pipe
4) Collapse	1) Low specific gravity or vacuum causing under pressure within riser pipe	1) Contamination of intervening water column		E	I	" "

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Riser
Component/Subsystem: Slurry Mixing Subsystem

Function: Monitor and Mix Waste Slurry Specific Gravity to provide proper flow rate through riser pipe and prevent damage to riser pipe.

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Low Pumping Rate	1) n of m Pump(s) Failure 2) Pump wear	1) Incorrect transfer rate	1) Pressure sensors 2) Flow Rate Sensors 3) PM/FL sensor	C C	III IV	Auto shutdown of affected riser pipe. Use redundant riser pipe Preventive maintenance
2) Excess Pumping Rate	1) Automated Pumping System Failure	1) Potential damage to riser pipe due to pressure differential (static head)	" "	C	III	Auto-Shutdown
3) No Pumping	1) Power Generation or Distribution Failure 2) Valve Failure	1) Total System Shutdown	" "	C C	II III	Power sources redundant

.ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Slurry Mixing Subsystem (Cont.)

Function: Monitor and Mix Waste Slurry Specific Gravity to provide proper flow rate through riser pipe and prevent damage to riser pipe.

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
4) Water Intake Flow Failure	1) Pipe rupture 2) Corrosion of line or storage vessel	1) High Specific Gravity Slurry Mix; Could lead to riser pipe failure; total system shutdown	1) Pressure sensors 2) Flow Rate Sensors 3) PM/FL sensor	D D	II III	Routine maintenance
5) Incorrect slurry specific gravity mix	1) Instrumentation failure 2) Processing error	1) Could lead to riser pipe failure	" "	C C	III III	
6) Leak	1) Pipe rupture /fracture 2) Corrosion of line or storage vessel	1) High or Low Specific Gravity Slurry Mix leading to transfer or riser pipe failure 2) Low transfer rate and contamination or area and/or personnel	1-3) " " 4) Visual Inspection	C D	II III	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Power Subsystem

Function: Provide electrical power for hydraulic pumps, navigation warning subsystems, communications subsystems, Position Keeping Subsystems

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) No or Limited Power	1) Diesel Generator failure	Low or no waste stream emplacement Loss of Navigation Early Warning Subsystems Loss of Collision Avoidance Beacons Loss of Station Keeping Subsystem, causing pipe riser to fail	Local Instrumentation for PM/FL	C	I	1) Power Systems must be redundant 2) UPS Power required for Early Warning, Emergency Lighting, Navigation Warning Systems, and PM/FL Instrumentation 3) Preventive Maintenance

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Terminus Mooring Subsystem

Function: Positioning of Lower Riser Terminus to ensure Emplacement on Site

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Inability to Position Correctly	1) Loss of Terminus Beacon (s) 2) Tractor Failure 3) SSP off station resulting from GPS failure	Inability to emplace within disposal site watchcircle; Contamination of non-approved area	PM/FL Instrumentation & Beacon Position Reference	C C D	III III IV	Redundancy
2) Inability to Moor	1) Mooring Cables Failure 2) Tractor Failure	" "	Instrumentation or ROV inspection	D D	II III	Redundancy

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Station Keeping Subsystem

Function: Keep Emplacement Platform (SSP or SB) on Station, Minimizing Lateral vs Location of Lower Terminus

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Inability to maintain position due to current or weather conditions	1) Thruster failure	1) Inability to position on site preventing emplacement initiation	GPS, Navigational subsystems, Terminus Beacons, and PM/FL Instrumentation	C	I	All applicable subsystems in redundant configurations
	2) Power failure	2) Inability to maintain position over site producing strain on riser pipes, with excessive tension loading or riser system causing structural failure.		C	I	
	3) GPS Failure			D	I	
	4) Computer/Software Failure			D	I	
2) Loss of motion compensation system	1) Cumulative fatigue cycles induced due to seastate, or hardware failure, or human error.	1) Fatigue failure leading to loss of riser system.	PM/FL Instrumentation	C	I	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser/SB
Component/Subsystem: SSP Stabilization Subsystem

Function: Trim Emplacement Platform (SSP or SB) for safe, controllable operation

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Loss of Ballast or Trim	1) Human error 2) Instrumentation error 3) Ballast or Load Shift	1) Potential loss of SSP 2) Induced strain on riser pipes leading to strain failure	PM/FL Instrumentation	D D D	I I I	Design margins and use of articulated motion compensation system
2) Compensation failure	1) Hardware failure 2) Human Error	1) Induced strain on riser pipes leading to breakage		D D	I I	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Pipe Riser
Component/Subsystem: Warning Subsystem

Function: To warn personnel and/or incoming vessel of emplacement platform (SSP or SB) presence to avoid collision.

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Loss of collision/ avoidance system and poor visibility /bad weather	1) Collision Avoidance or Power System Failure with poor visibility	1) Potential collision if incoming vessel does not detect SSP and communications are lost.	1) Self test 2) Operator Observations	D	II	1) Collision Avoidance System 2) Redundancy 3) on UPS
2) Loss of communications	1) Communications Subsystem and/or power subsystem failure with poor visibility	1) Inability to warn incoming vessel if it does not spot SSP	1) Periodic test and/or operator observations	D	II	1) Communication system redundancy 2) Communication on UPS power 3) Power subsystem redundancy and preventive maintenance

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Transport to Site
Component/Subsystem: Hull

Function: 1) Foundation for Ship/Barge/Glider Subsystems
2) Contain (some configurations) waste stream during transport

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
Rupture	Collision	1) Loss of transport vessel 2) Potential contamination spill	Inspection	E	I	Double hull

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Transport to Site
Component/Subsystem: Waste Stream Container

Function: Contain waste during transport

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Rupture	1) Damage in handling	1) Contamination of vessel, water in unauthorized area	1) Inspection 2) Sensing subsystems	D	III	1) Material selection 2) Handling procedures 3) Design margin 4)Vendor certification of containers
		2) Potential methane explosion in presence of spark or static electricity	" "			1) Spark suppression 2) Venting of volatile gasses

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Transport to Site
Component/Subsystem: Navigation

Function: Guide vessel to location over authorized dumping location

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Incorrect or no location identified	1) Hardware failure 2) Human error	1) Transport to wrong site or more probably near but incorrect sight; Potential to emplace at unauthorized location 2) Transport may cross into shipping lanes presenting hazard to navigation	Comparison to back-up systems or on-site markers (or riser platform)	D D	III III	Some back-up method must be provided

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Transport to Site
Component/Subsystem: Propulsion/Steering

Function: Propel vessel/barge to dumping site and/or loading area

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Propulsion/ Steering failure	1) Component failure 2) Fuel failure	1) Potential navigation hazard	Operator detection	D	III	Navigation signaling; communication
		2) Cueing failure		E	IV	

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Transport to Site
Component/Subsystem: Trim/Buoyancy

Function: Maintain vessel sea worthiness

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Loss of Trim	1) Collision	1) Potential loss of vessel or barge 2) Potential unintentional barge/vessel separation 3) Potential waste spill 4) Potential hazard to navigation	Sensor monitoring system Crew	D	II	Compartmentized design minimizes possibility and impact

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Transport to Site
Component/Subsystem: Vessel/Barge Interface

Function: Maintain "Connection" between vessel and barge as long as desired

Failure Mode	**Failure Causes and Mechanisms**	**Failure Effects**	**Failure Detection Method**	**PO**	**SC**	**Failure Prevention and Compensating Features**
1) Transport Interface System	1) TUG Interface	1) Loss of barge during transport	Pre-mission inspection	D	II	1) Design analysis 2) Qualification test program 3) Preventive maintenance 4) If adrift, take under tow

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Waste Stream Handling @ Port
Component/Subsystem: Fill Monitoring Subsystem

Function: 1) Monitor and control transfer of waste stream from trucks to dock side storage
2) Monitor and control transfer of waste stream from dock side storage to flexible bladders or vessel storage

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Overflow	1) Sensor failure 2) Operator error 3) Processor/Software error	1) Dock or vessel contamination 2) Methane explosion in presence of spark	1) Operator inspection 2) Back-up instrumentation	C D D	III III III	1) Redundant fill monitoring 2) Spark Suppression

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Waste Stream Handling @ Port
Component/Subsystem: Waste Storage Containers
Function: Store waste stream between system operations

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Rupture	1) Corrosion 2) Manufacturing defect	1) Contamination of dock, vessel, or water in unauthorized area 2) Potential methane explosion in presence of spark	1) Inspection 2) Gas Sensing subsystems " "	D D	III III	1)Material selection 2) Handling procedures 3) Design margin 4) Vendor certification of containers 5) Spark suppression

ABYSSAL PLAINS WASTE ISOLATION PROJECT
FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

Mission Segment Name: Waste Stream Handling @ Port
Component/Subsystem: Transfer Mechanism

Function: 1) Transfer waste stream between trucks and dock side storage containers
2) Transfer waste stream between dock side storage containers and flexible bladders or vessel storage containers

Failure Mode	Failure Causes and Mechanisms	Failure Effects	Failure Detection Method	PO	SC	Failure Prevention and Compensating Features
1) Loss of transfer efficiency	1) One or more pump failures	1) Transfer rate low leading to Queuing failure	Transfer flow monitoring failure	C	IV	1) Fault tolerant design 2) Extensive design analysis and test program 3) Redundant power sources 4) Preventive maintenance
	2) Mechanical wear (lowering efficiency)			C	IV	
	3) Partial pump or mechanical system power failure			C	IV	
	4) Some processor/ software functions			D	IV	
2) Total loss of transfer capability	1) Common pump (or hydraulic element) failure	1) System stoppage		D	III	
	2) Mechanical breakage of conveyor/bucket system (some configurations)			D	III	1) Fault tolerant design 2) Extensive design analysis and test program 3) Redundant power sources 4) Preventive maintenance
	3) Major pump or mechanical system power failure			D	III	
	4) Processor failure			D	III	